1982

Dual-phase nozzle flow.

Nollie, Thomas C.

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

DUAL-PHASE NOZZLE FLOW

by

Thomas C. Nollie, Jr.

Ocotber 1982

Thesis Advisor: J. F. Sladky

Approved for public release; distribution unlimited.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Dual-Phase Nozzle Flow		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; October 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas C. Nollie, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE October 1982
		13. NUMBER OF PAGES 195
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dual-phase
Bi-phase
Two-phase

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A review of the dual-phase power system was made. This study focused on the multi-component nozzle of this dual-phase system. First, an existing computer code predicting the nozzle performance was updated, and second a series of experimental tests on a variable area, two-dimensional nozzle was performed to verify the computer code.

Approved for public release; distribution unlimited.

Dual-Phase Nozzle Flow

by

Thomas C. Nollie, Jr.
Lieutenant, United States Navy
B.S., United States Naval Academy, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
October 1982

ABSTRACT

A review of the dual-phase power system was made. This study focused on the multi-component nozzle of this dual-phase system. First, an existing computer code predicting the nozzle performance was updated, and second a series of experimental tests on a variable area, two-dimensional nozzle was performed to verify the computer code.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. DUAL-PHASE CYCLE

The dual-phase nozzle is a key element in the dual-phase engine concept. This nozzle will be studied in detail, but first a review of the dual-phase cycle will be carried out from information obtained from References 1 and 2.

Reference 1 describes the dual-phase engine. It is a new concept which operates on a mixture of two fluids or two phases of one fluid. This cycle employs a high-torque/low-rpm impulse turbine which eliminates the requirement for speed reduction needed in a conventional steam turbine. This allows for direct drive of a ship's propeller with no gear reduction. This is ideally suited for marine propulsion, reducing weight, noise, and volume.

The dual-phase concept is a modified Rankine cycle with subtle differences of extreme importance. In a normal steam turbine the working fluid enters a turbine through a nozzle where the kinetic energy of the working fluid is converted to a mechanical form. The dual-phase system introduces a second fluid prior to entry into the nozzle. This fluid is of higher vapor pressure than the steam and therefore remains in the liquid state throughout the cycle. Section A will describe this two-component cycle while section B will do the same for a single-component system. The dual-phase

system can be divided into the two groups illustrated in Figure 1. Single-component flow can be further divided into three categories.

A. TWO-COMPONENT

A two-component mixture is one in which the low vapor pressure liquid and a high vapor pressure liquid are of different chemical compounds. Some fluid combinations which have been considered are steam-krytox, steam-caloria, steam-lead, bismuth eutectic, and dow-therminol. A schematic flow diagram and process representation on the T-S diagram are shown in Figures 2 and 3 for the two-phase engine cycle using a "two-component" mixture. The liquid phase is lithium carbonate and vapor phase is steam. To illustrate the overall advantages of the two-phase engine cycle a discussion on the theory of operation will be presented using a two-component mixture and Figures 2 and 3.

The major component of the dual-phase system is the nozzle. A mixer area is located prior to the nozzle inlet. A high vapor pressure liquid is placed in contact with the low vapor pressure liquid in this area. A high pressure vapor liquid mixture is formed. Since the temperature of the liquid is greater than temperature of the water, heat is transferred to the water causing it to vaporize to point 1. Figure 4 illustrates the temperature and state point from the inlet of the mixture area to the nozzle exit. This mixture is

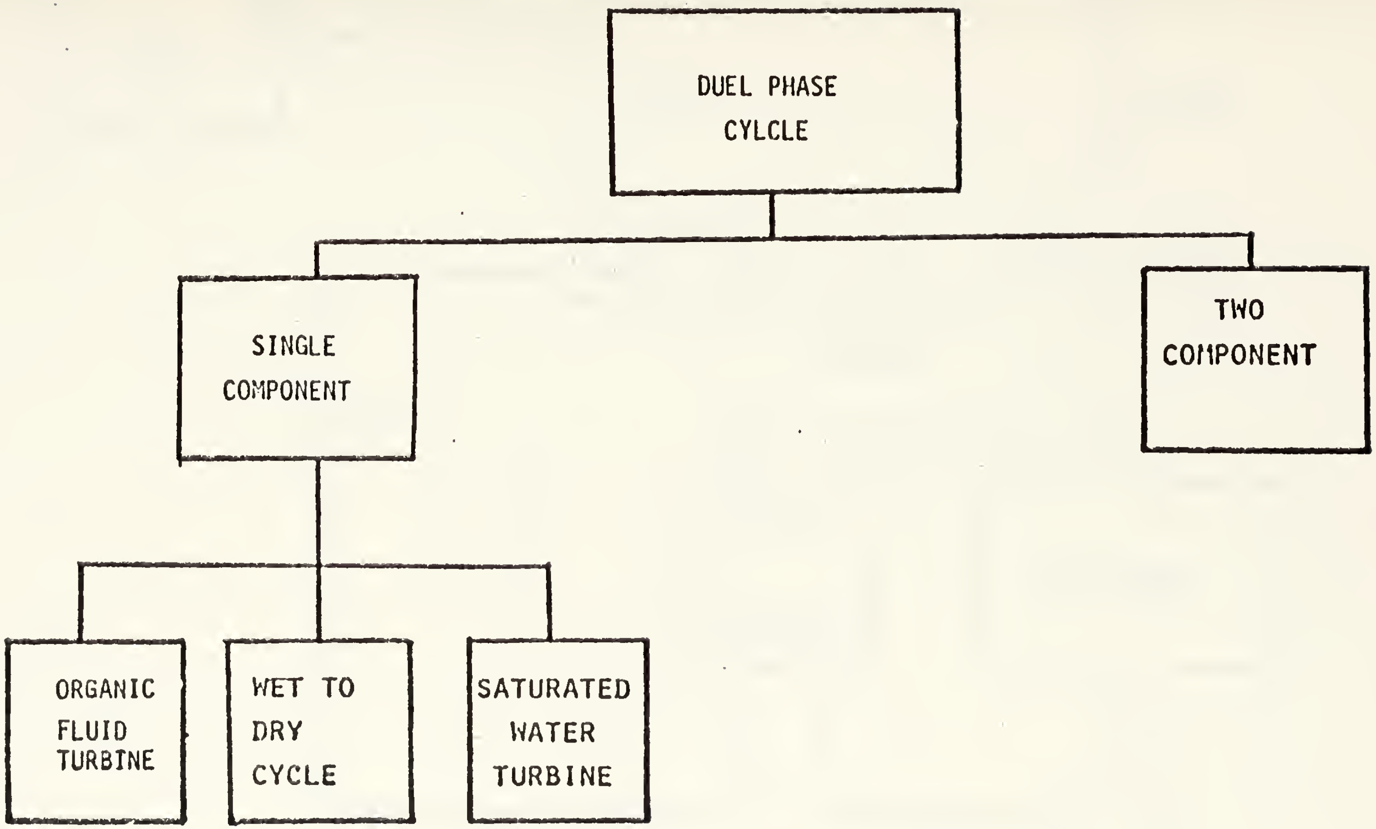


Figure 1. Division of the Dual-Phase Cycle

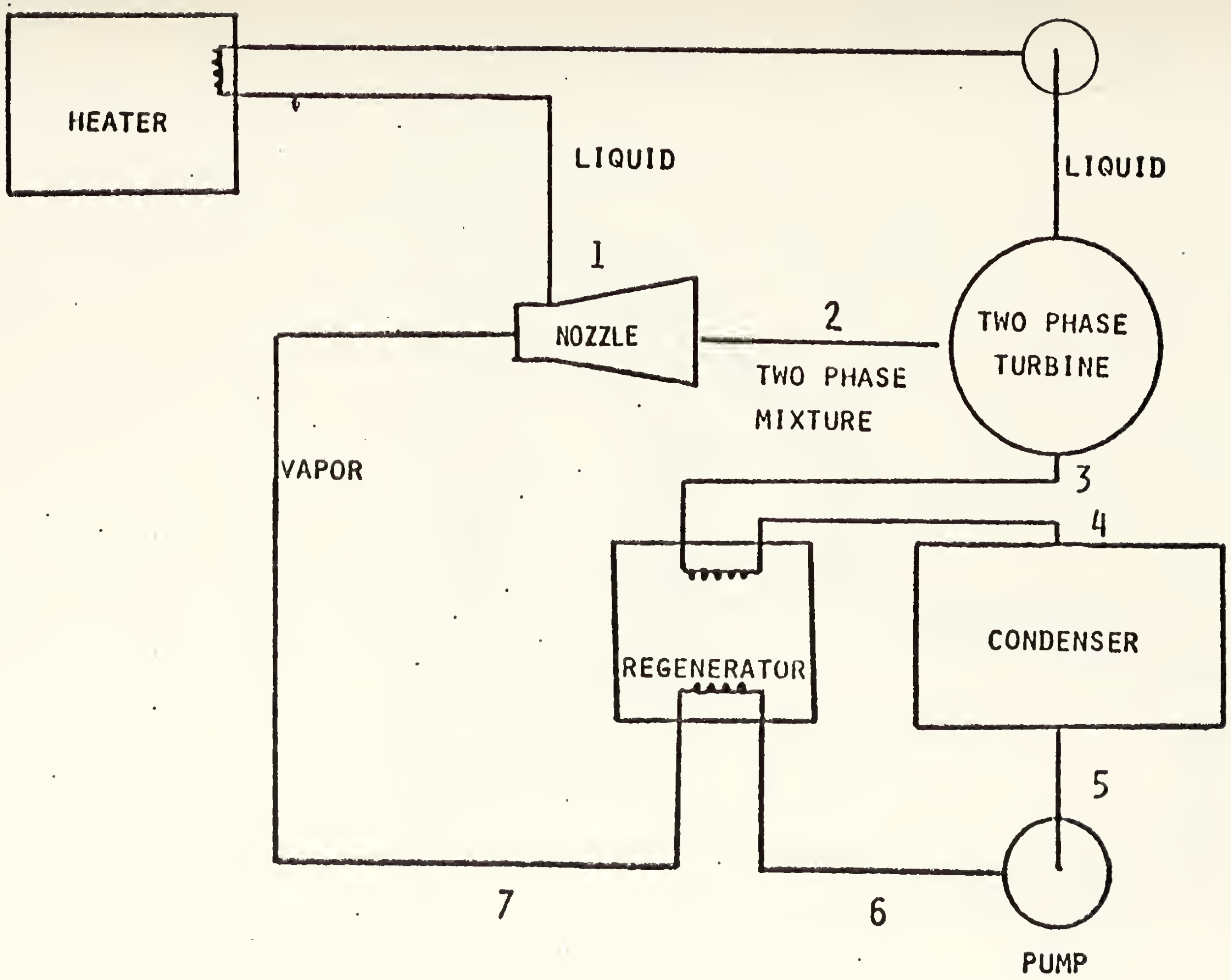


Figure 2. Dual-Phase Two-Component System

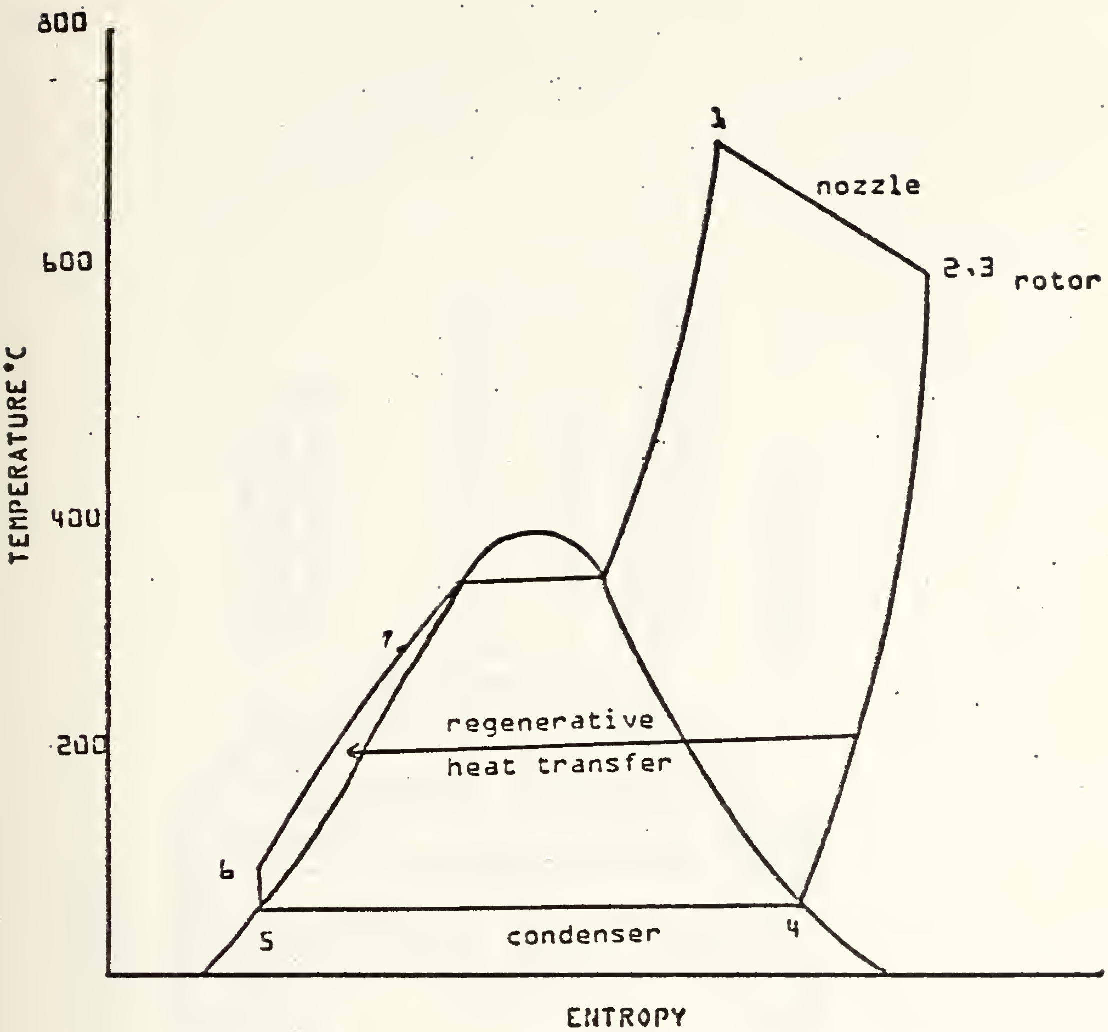


Figure 3. Dual-Phase Two-Component T-S Diagram

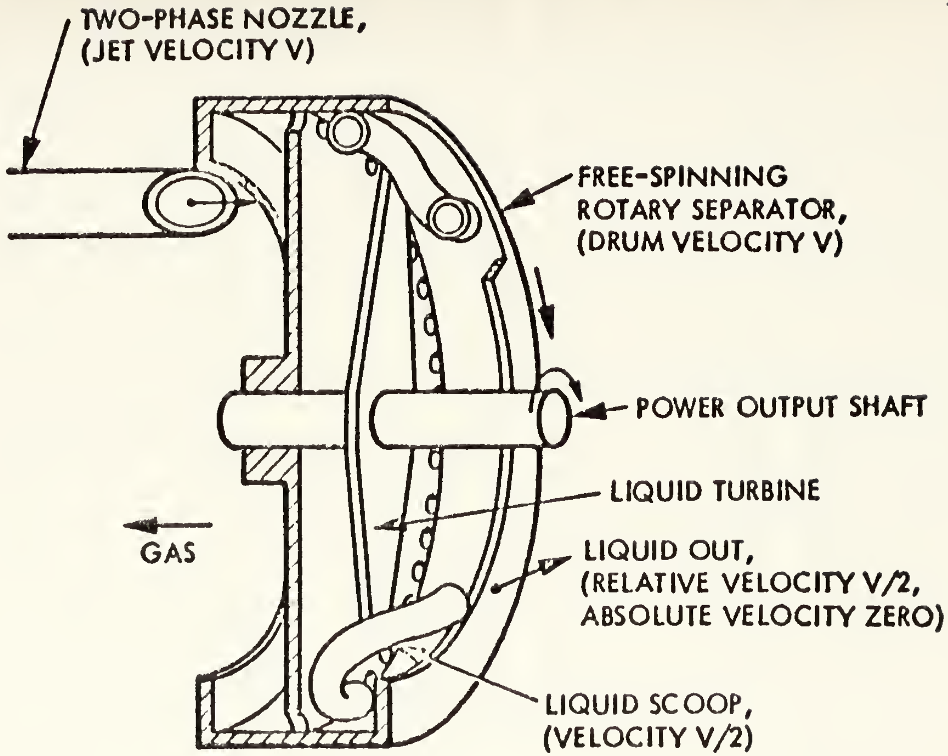
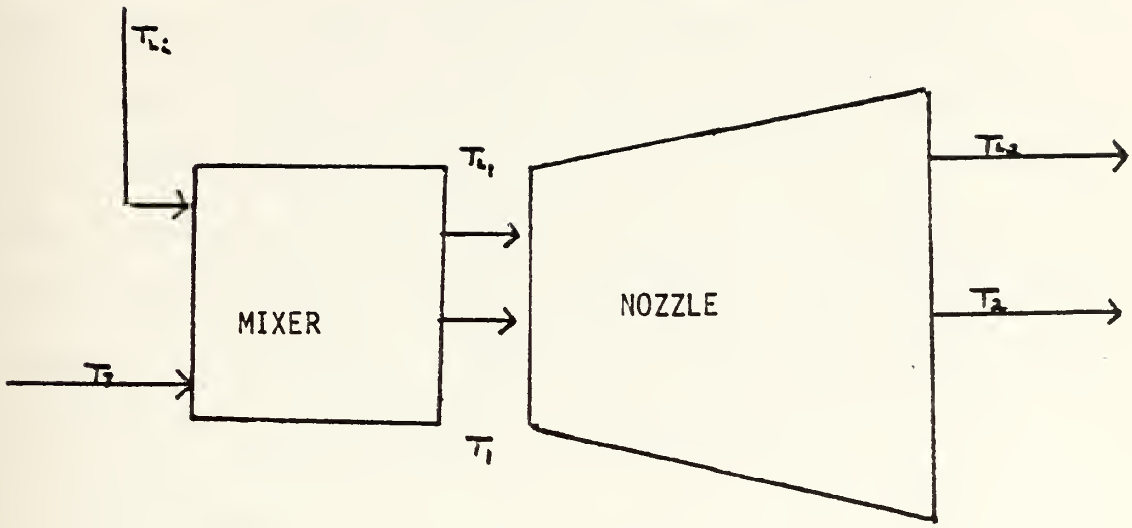


Figure 4. Liquid Impulse Turbine Schematic

expanded to a low pressure at the nozzle exit. The expanding vapor transfers momentum to the liquid droplets, while the droplets transfer heat to the vapor. This tends to apaproach isothermal expansion through the nozzle, point 2. After leaving the nozzle, the liquid droplets are separated from the vapor by a rotary separator located on the turbine. The rotating drum turns at close to the nozzle's exit velocity. Hence there is very little friction loss between the separated liquid and the drum wall. The centrifugal acceleration produces a very clean separation of vapor and liquid. The liquid traveling with the rim of the rotating drum transfers axially through holes in the separator disc and subsequently enters the liquid turbine proper. The kinetic energy of the liquid is converted to shaft horsepower by the liquid turbine. Figure 5 illustrates the dual-phase liquid impulse turbine assembly. The vapor remains superheated as a consequence of the heat transfer from the liquid. The vapor flows from the separator, point 3, through a regenerator where heat is transferred to the condensate. The vapor is condensed, point 5; pumped to nozzle pressure, point 6; and passed through the regenerator for heating. Heat is added between point 6 and point 1 in two methods. The regenerator adds heat to the condensate by using the steam from the turbine rotor, point 7. The remainder of heat, point 7 to 1, is added by the heated liquid mixed with the condensate in the mixer. The water is vaporized by direct-contact heat transfer.



where T_{L_i} = Temp of liquid entering mixer

T_7 = Temp of water entering mixer

$T_{L_i} > T_1$

T_2 = Temp of steam leaving the nozzle

T_{L_2} = Temp of liquid leaving the nozzle

Figure 5. Temperature & State Point Diagram for the Mixture & Nozzle

In the nozzle most of the thermal energy of the steam is converted to kinetic energy of the liquid droplets. This acceleration of the liquid by the vapor in the two-phase nozzle provides the kinetic energy to drive the liquid impulse turbine. The liquid velocities involved are relatively low as compared to velocity of the vapor. Thus, the output of the impulse hydraulic turbine will be high torque/low rpm. This conversion of the liquid kinetic energy to shaft power at high torque with low rpm appears to have direct application to naval propulsion.

B. ONE-COMPONENT

A one-component system is one in which the working fluid is of the same chemical compound. One of the simplest dual-phase one-component systems is illustrated in Figures 6 and 7. The working fluid is heated to saturation temperature by some type of heat source. Heat sources applicable to this case are geothermal power plants, engine exhaust, industrial waste-heat recovery, and bottoming cycles for steam and gas turbine plants. This working fluid, at saturated liquid conditions, with small amounts of vapor is expanded through a two-phase nozzle. As the expansion process takes place ,the liquid partially vaporizes and accelerates the remaining liquid phase in the nozzle. The dual-phase mixture enters the rotary separator and the same process occurs as mentioned in section A. Since the liquid phase is of a much higher

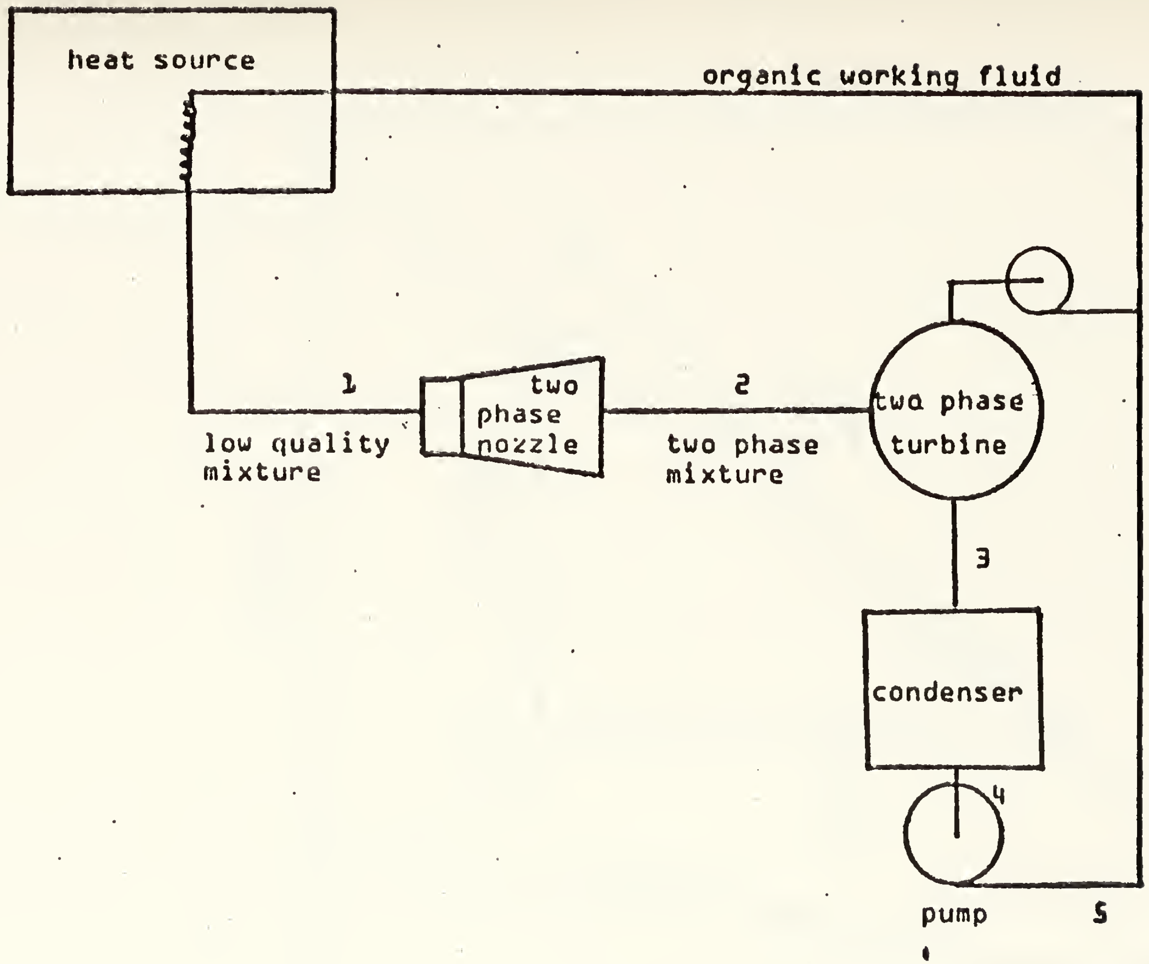


Figure 6. Dual-Phase Single-Component System

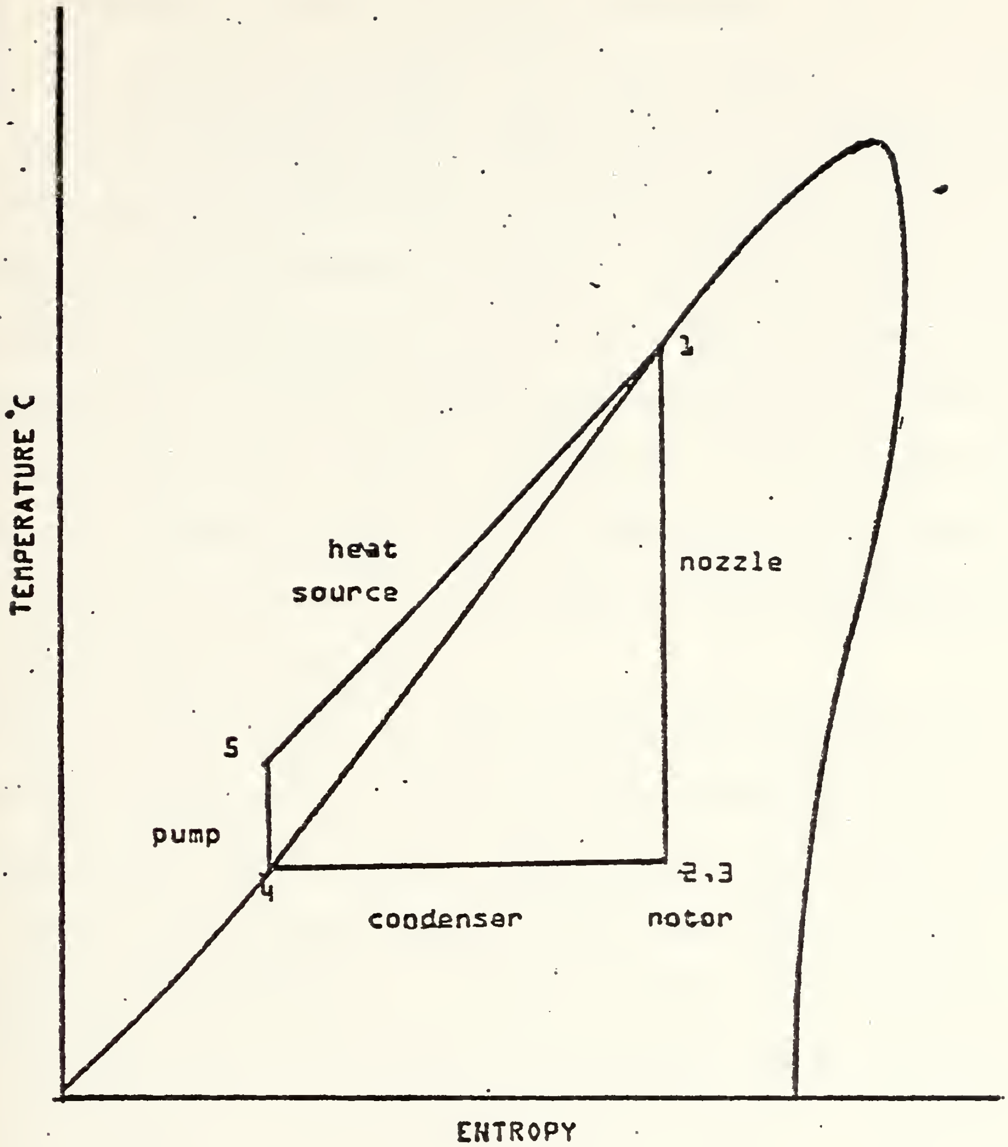


Figure 7. Dual-Phase Single-Component T-S Diagram

density than the vapor, the liquid velocities are relatively low as compared to the velocity of the vapor. Thus the output of the turbine will again have high torque at low rpm. After leaving the turbine the vapor mixture is condensed and the condensate is pumped back to the heat source. The cycle is shown on a T-S diagram in Figure 6. The state points are numbered to correspond with Figure 5. The dual-phase nozzle expansion takes the fluid from a saturated liquid, point 1, to a dual-phase flow, point 2. The flow is decelerated in the rotor; condensed, point 4; and pumped back to nozzle inlet pressure at point 5. The liquid is then reheated by the source fluid to point 1.

Another application of the one-component two-phase cycle is the wet-to-dry cycle. If the initial temperature of the working fluid is sufficiently high and the saturation curve has a positive saturated liquid slope the working fluid can be expanded to dry vapor. Figure 8 is the T-S diagram for a wet-to-dry cycle. The fluid is expanded from saturated liquid at point 1 to saturated vapor at point 2. The vapor drives an impulse rotor and leaves the rotor slightly superheated at point 3. The vapor is condensed to point 4 and pumped back to the nozzle inlet pressure at point 5.

C. ADVANTAGES

The advantage of the dual-phase cycle with respect to marine application is the ability to achieve low shaft speed

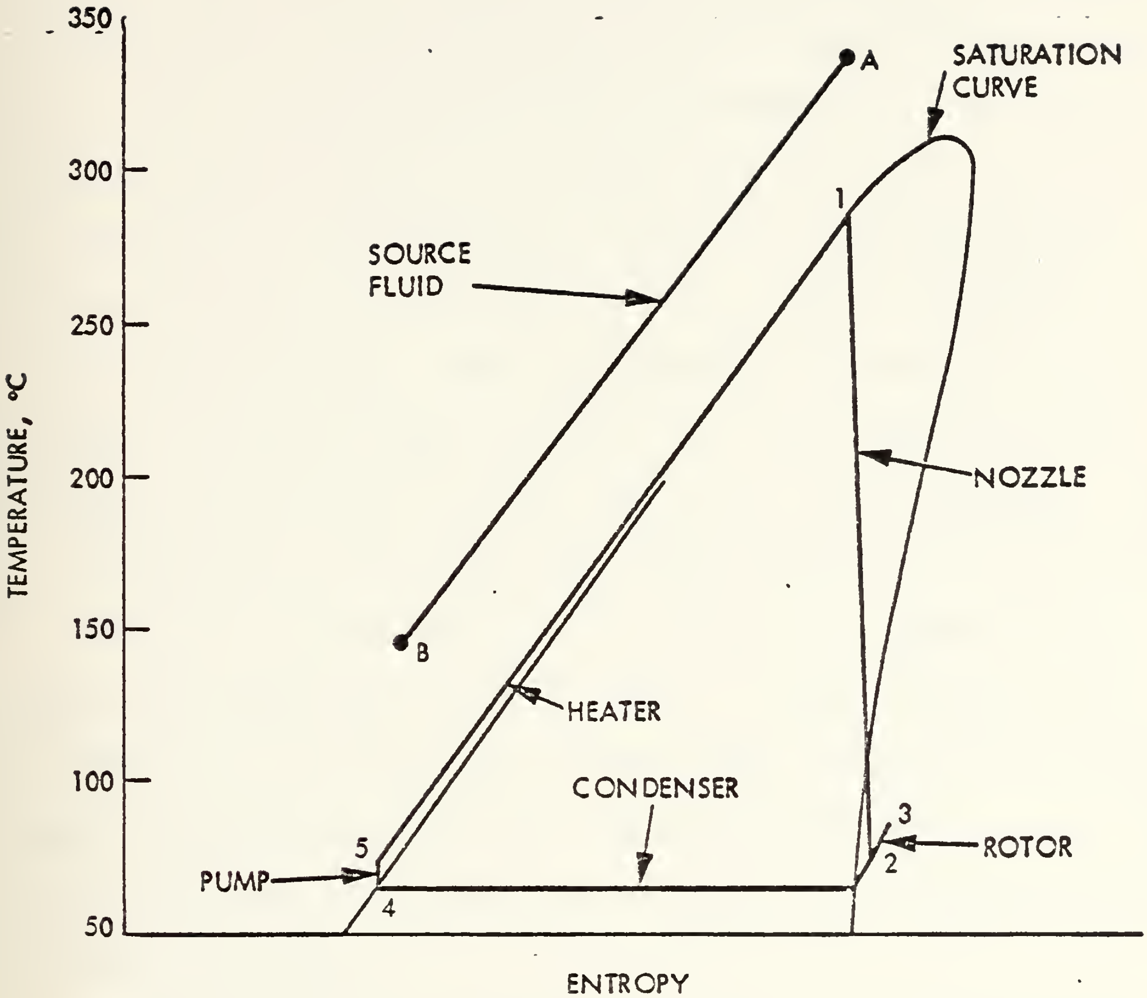


Figure 8. Wet-to-Dry T-S Diagram

in a small turbine engine. For example a steam turbine of 150-kw shaft horsepower using the temperature given in Figure 2 would have a speed of about 60,000 rpm. A comparable two-phase turbine would operate at approximately 10,000 rpm. There is also an efficiency advantage. At temperature corresponding to Figure 2, a steam Rankine cycle would have an efficiency of approximately 28% where-as the two-phase cycle would have an efficiency of 37%. This is assuming equal turbine efficiencies. The two-phase cycle also allows for control of turbine speed because the vapor/liquid mixture ratio can be varied to change the nozzle exit velocity. This is a capability unavailable in a conventional steam turbine.

Both of the dual-phase concepts can be thought of as a form of a regenerated Rankine cycle. The dual-phase cycle by control of liquid/vapor mixture ratio enhances the overall power system controlability. The T-S relationship for a dual-phase two-component engine cycle compared to a Rankine cycle is shown in Figure 9.

Two design studies References 1 and 2, have shown potential advantages in the two-phase engine cycle as compared to the conventional Rankine cycle for marine propulsion. The following advantages were noted:

1. High Efficiency - Full load output power performance gains ranging from 20 to 50 percent was found.

2. Direct Drive - Direct drive at speeds ranging from 90-4500 rpm was found possible with a single-stage turbine.

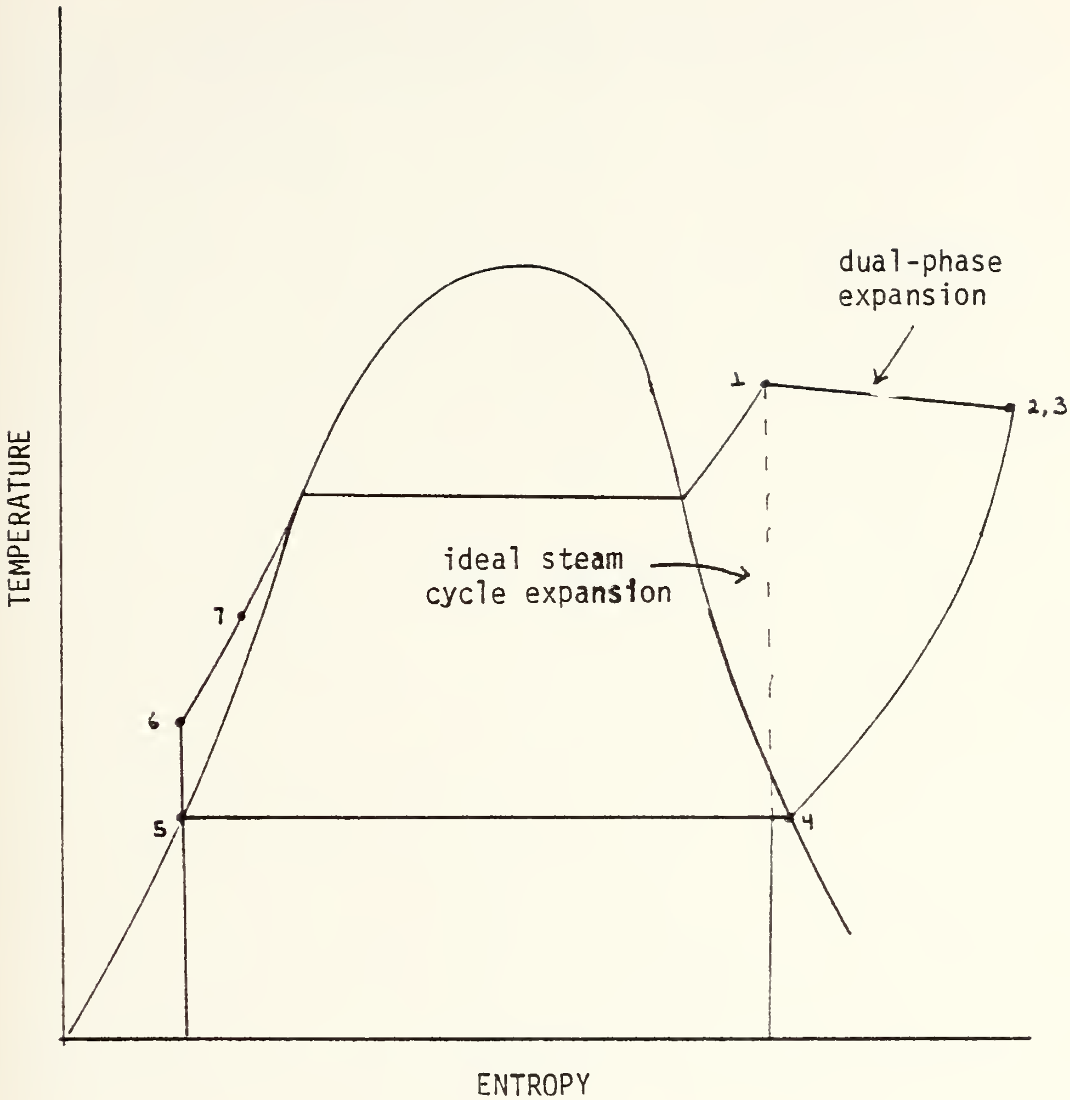


Figure 9. T-S Comparison of Dual-Phase Two-Component Cycle & Rankine Cycle

3. Reduced Volume - Volume reduction of 30 percent were estimated.

4. High Part-Load Efficiency - Variable mass ratio enabled part-load (cruise) efficiency gain of as much as 100 percent.

II. DUAL-PHASE NOZZLE THEORY

The flow phenomenon of a two-phase mixture has been analyzed in Reference 1. It is repeated as follows. The problem is illustrated in Figure 10. A spatially uniform two-component mixture of liquid drops and gas enters a nozzle at high pressure and low velocity and expands to low pressure and high velocity. The objective of the analysis is to determine, for a specified pressure the drop diameter D and the temperatures T_g and T_L, velocities V_g and V_L and flow rates $\dot{m}_g$ and $\dot{m}_L$ of the gas and liquid phases, respectively, at each station in the nozzle given the initial values of D, T_g, T_L, V_g, V_L, the total flow rate, and the properties of the fluids.

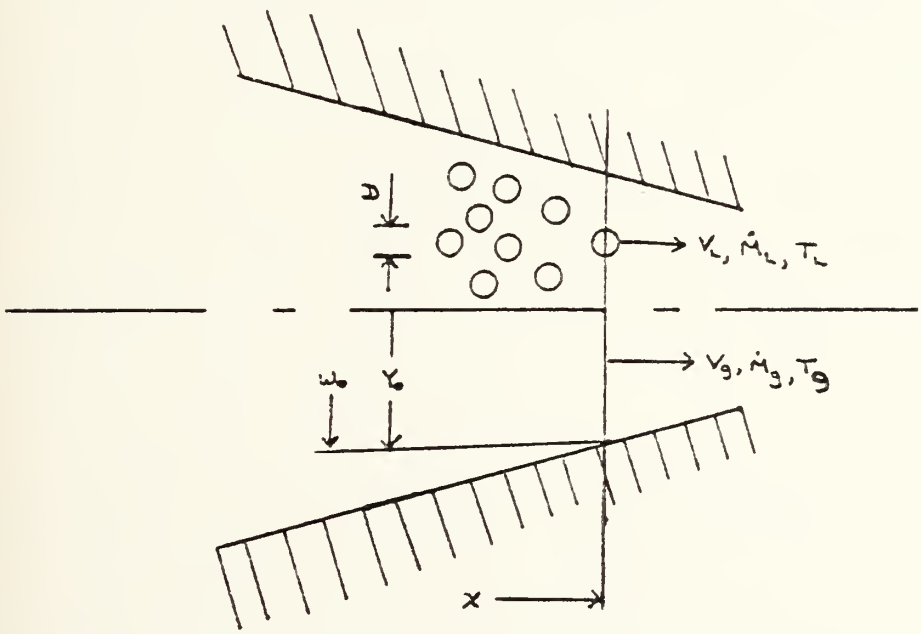


Figure 10. Dual-Phase Nozzle Flow Geometry & Nomenclature

The five relations employed to compute the five unknowns D, T_g, T_L, V_g, and V_L, are (1) the momentum equation for the mixture, (2) the energy equation for the mixture, (3) the drop drag equation, (4) the drop heat transfer equation, and (5) the drop breakup criterion. Solubility and vapor pressure relations provide the flow rate ratio $\dot{m}_g/\dot{m}_L$.

A. ASSUMPTIONS

The assumptions employed in the two-component analysis are as follows:

1. The liquid is uniformly dispersed as spherical drops all of the same diameter.
2. The drops break up to limit the Weber number to 6.
3. There are no external forces acting on the two-phase mixture other than pressure and wall shear, and there is no heat transfer to or from the mixture.
4. The flow is one-dimensional.
5. The drops are large enough for the surface curvature to have negligible effect on the vapor pressure of the liquid and for the surface energy to be negligible.
6. The drops are isothermal.
7. The gas mixture obeys the additive-pressure law.
8. The partial pressure of the predominantly liquid component in the liquid is given by Raoult's Law.
9. The concentration of the predominantly gaseous component in the liquid is given by Henry's Law.

10. The volume of the liquid solution is equal to the sum of the volumes of the pure liquids.

Assumption 1 restricts the analysis to nozzles having spatially uniform injection of the liquid into the gas and operating at gas-to-liquid volume ratios greater than unity. Assumption 2, the drop breakup criterion, states that drop diameter is limited to a value D for which $W_e = \rho_g V_g^2 D/2 = 6$. Thus

$$D_{max} = \frac{12\sigma}{\rho_g V_s^2} \tag{1}$$

where ρ_g is the gas density, V_s is the slip velocity $V_g - V_L$, and is the liquid surface tension. The form of Eq. (1) is physically reasonable in that the Weber number is proportional to the ratio of stagnation pressure $\rho_g V^2{}_s/2$ to surface tension pressure $4\nabla/D$. Hence, a drop would be expected to flatten and breakup at a sufficiently high value of W_e. This has been verified experimentally and the critical Weber number found to be 6, within a factor of about two. An additional restriction is that for actual breakup to occur, the time spent at a Weber number exceeding 6 must be longer than the natural period of oscillation of the drop, $\pi(\rho_L D^3/\ \ )^{1/2}/4$, where ρ_L is the density of the liquid. This requirement is met only in two-phase nozzles longer than about 10 in. and Assumption 2 may cause the analysis to overestimate the exit velocity by increasing amounts as the nozzle length decreases below 10 in.

Assumption 3 excludes magnetohydrodynamic and mechanical body forces. The exclusion of wall heat transfer is correct for the insulated nozzles of interest for power systems. In addition, the relatively high velocity results in short residence lines in the nozzle proper.

Assumption 4 is closely met in practical nozzles since good performance requires small wall angles, large throat radius of curvature, and uniformly distributed injection of the fluids at the nozzle entrance.

Assumption 5 is valid for the drop sizes of 0.001 to 0.010 in. produced by the Eq. (1) breakup criterion. Assumption 6 is valid because of the rapid internal circulation in drops. Assumption 7 introduces negligible error in most cases of practical interest since the vapor pressure of the liquid is small and needs only to be evaluated approximately.

Assumptions 8, 9, and 10 are either valid, or cause little error, for fluids of low miscibility, which are the fluids of interest.

B. DERIVATION OF EQUATIONS FOR FREE-STREAM FLOW

1. Continuity

Referring to Figure 1, the nozzle flow area A is equal to the gas flow area $\dot{m}_g/\rho_g V_g$ plus the liquid flow area $\dot{m}_L/\rho_L V_L$. Thus

$$A = \dot{m}_g\left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l}\right) \qquad (2)$$

where r is the mass mixture ratio $\dot{m}_L/\dot{m}_g$.

2. Momentum

By Assumption 3, the only force acting on the free-stream flow is that due to the pressure gradient. If $\dot{M}$ is the momentum flux at flow area A, the change in momentum flux across pressure increment dp is

$$d\dot{M} = -A\,dp \tag{3}$$

The momentum flux can be written as the sum of the momentum fluxes of the gas and liquid. Thus,

$$\dot{M} = \dot{m}_g V_g + \dot{m}_l V_l \tag{4}$$

If the flow were allowed to continue at constant pressure, V_g and V_L would become equal to each other at the mass-weighted mean velocity $\overline{V}$. Since for this process, $d\dot{M} = 0$, the value of $\overline{V}$ is given by

$$(\dot{m}_g + \dot{m}_l)\overline{V} = \dot{m}_g V_g + \dot{m}_l V_l \tag{5}$$

or

$$\overline{V} = \frac{V_g + rV_l}{1 + r} \tag{6}$$

Thus, the momentum flux can be written

$$\dot{M} = (\dot{m}_g + \dot{m}_l)\overline{V} \tag{7}$$

Since $\dot{m}_g + \dot{m}_L$ is constant, the change in momentum flux is

$$d\dot{M} = (\dot{m}_g + \dot{m}_l)d\overline{V} \tag{8}$$

Substituting Eqs. (8) and (2) into Eq. (3), $d\overline{V}$ can be written

$$d\overline{V} = -\frac{1}{1 + r}\left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l}\right) dp \tag{9}$$

The slip ratio is defined as

$$s = V_s/\bar{V} = (V_g - V_l)/\bar{V} \tag{10}$$

This equation can be combined with Eq. (6) to give V_g and V_L in terms of $\bar{V}$:

$$V_g = \left(1 + \frac{rs}{1+r}\right)\bar{V} = a\bar{V} \tag{11}$$

$$V_l = \left(1 - \frac{s}{1+r}\right)\bar{V} = b\bar{V} \tag{12}$$

The gas density can be expressed as

$$\rho_g = W_g p/RT_g \tag{13}$$

where W_g is the effective molecular weight of the gas mixture and R is the universal gas constant. Eq. (13) is the definition of the effective molecular weight W_g, which is the quantity that gives the actual gas density when substituted in Eq. (13).

Substituting Eqs. (11) - (13) into Eq. (9), the differential momentum equation is

$$2\bar{V}d\bar{V} = d\bar{V}^2 = -\frac{2}{1+r}\left(\frac{RT_g}{aW_g p} + \frac{r}{b\rho_l}\right)dp \tag{14}$$

The quantities a and b are slowly varying because s is typically only 0.1 to 0.3 and slowly varying. The quantities r, T_g, W_g and ρ_L are also slowly varying. Integrating

Eq. (14) over a pressure increment Δp, for which a, b, r, T_g, W_g, and ρ_L are constant to within the desired accuracy, the change in $\overline{V}^2$ is

$$\Delta\overline{V}^2 = -\frac{2}{1+r_m}\left(\frac{RT_{g_m}}{a_m W_{g_m}} \log_e \frac{p + \Delta p/2}{p - \Delta p/2} + \frac{r_m \Delta p}{b_m \rho_{l_m}}\right) \tag{15}$$

All quantities other than pressure can be taken outside the integral and evaluated at their mean values (denoted by sub script m) corresponding to the mid-interval pressure p. Thus,

$$\Delta\overline{V}^2 = -\frac{2}{1+r_m} \times \left(\frac{RT_{g_m}}{a_m W_{g_m}}\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} \frac{dp}{p} + \frac{r_m}{b_m \rho_{l_m}}\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} dp\right) \tag{16}$$

(16)

Performing the integrations,

$$\Delta\overline{V}^2 = -\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} \frac{2}{1+r}\left(\frac{RT_g}{aW_g p} + \frac{r}{b\rho_l}\right) dp \tag{17}$$

Equation (17) is the final form of the momentum equation.

3. <u>Energy</u>

The enthalpy change of the mixture between state 1 (the beginning of pressure interval Δp) and state 2 (the end

of the interval) can be evaluated in two steps: (1) phase change at ρ_1, T_{g_1}, T_{L_1} and (2) change to ρ_2, T_{g2}, T_{L2}, at fixed composition.

The enthalpy change for step 1 is

ΔH_1	=	amount of A vaporized	X	enthalpy required to vaporize and heat unit mass of A from T_L to T_{gL}
	+	amount of B vaporized	X	enthalpy required to vaporize and heat unit mass of B from T_{L_1} to T_{g_1}
	+	amount of A and B	X	kinetic energy required to accelerate unit mass from V_{L_1} to V_{g_1}

or

$$\begin{aligned}\Delta H_1 = {} & (\dot{m}_{a_{g_2}} - \dot{m}_{a_{g_1}})\,[L_{a_1} + c_{a_{g_1}}(T_{g_1} - T_{l_1})] \\ & + (\dot{m}_{b_{g_2}} - \dot{m}_{b_{g_1}})\,[L_{b_1} + c_{b_{g_1}}(T_{g_1} - T_{l_1})] \\ & + (\dot{m}_{g_2} - \dot{m}_{g_1})(V_{g_1}^2 - V_{l_1}^2)/2\end{aligned} \tag{18}$$

where L and c are latent heat and specific heat, respectively.

Introducing more compact notation.

$$\begin{aligned}\Delta H_1 = {} & \Delta\dot{m}_{a_g}(L_{a_1} + c_{a_{g_1}}\delta_1 T) \\ & + \Delta\dot{m}_{b_g}(L_{b_1} + c_{b_{g_1}}\delta_1 T) + \frac{\Delta\dot{m}_g\delta_1 V^2}{2}\end{aligned} \tag{19}$$

The enthalpy change for step 2 is evaluated from the temperature, pressure, and velocity changes, with properties evaluated at mean T and ρ for the interval.

$$\Delta H_2 = \dot{m}_{g_2}\left[c_{g_m}(T_{g_2} - T_{g_1}) + \frac{1}{2}(V_{g_2}^2 - V_{g_1}^2)\right]$$

$$+ \dot{m}_{l_2}\left[c_{l_m}(T_{l_2} - T_{l_1}) + \frac{p_2 - p_1}{\rho_{l_m}} + \frac{1}{2}(V_{l_2}^2 - V_{l_1}^2)\right] \tag{20}$$

$$= \dot{m}_{g_2}\left(c_{g_m}\Delta T_g + \frac{\Delta V_g^2}{2}\right) + \dot{m}_{l_2}\left(c_{l_m}\Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_l^2}{2}\right) \tag{21}$$

By Assumption 3, no work is done by the free-stream flow and no heat is transferred to it. Hence,

$$\Delta H_1 + \Delta H_2 = 0 \tag{22}$$

Substituting Eqs. (19) and (21) into Eq. (22) and solving for ΔT_g gives the energy equation for the mixture:

$$\Delta T_g = -\frac{1}{c_{g_m}}\left[\frac{\Delta V_g^2}{2} + r_2\left(c_{l_m}\Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_l^2}{2}\right) + \frac{\Delta\dot{m}_g\delta_1 V^2}{2\dot{m}_{g_2}} + \frac{\Delta\dot{m}_{a_g}}{\dot{m}_{g_2}}\left(L_{a_1} + c_{a_{g_1}}\delta_1 T\right) + \frac{\Delta\dot{m}_{b_g}}{\dot{m}_{g_2}}\left(L_{b_1} + c_{b_{g_1}}\delta_1 T\right)\right] \tag{23}$$

4. Drag

Although no force other than pressure acts on the free-stream flow as a whole, a drag force exists between

the phases. Hence, a second momentum equation must be witten using as the control volume the boundary between the phases.

The two forces acting on each liquid drop are the buoyancy due to the pressure gradient and the drag due to the relative gas velocity. The sum of these is equal to the mass times the acceleration of the drop. Thus, for a single drop.

dynamic pressure of relative gas flow	X	drag coefficient	X	frontal area of drop

- volume of drop	X	pressure gradient	=	mass drop drop	X	acceleration of drop

or

$$\left(\frac{1}{2}\rho_g|V_s|V_s\right)C_D\frac{\pi D^2}{4}-\frac{\pi D^3}{6}\frac{dp}{dx} = \left(\frac{\pi D^3}{6}\rho_l\right)\left(V_l\frac{dV_l}{dx}\right) \tag{24}$$

The absolute value sign in the first term makes the drag force positive when $V_g > V_L$ and negative when $V_g < V_L$.

Solving Eq. (24) for dV_L,

$$dV_l = \frac{3\rho_g|s|s\bar{V}^2C_D dx}{4\rho_l V_l D} - \frac{dp}{\rho_l V_l} \tag{25}$$

Differentiating Eq. (12), dV_L can also be expressed in terms of s, r, and $\overline{V}$. Thus,

$$dV_l = b d\overline{V} + \overline{V}\left[\frac{s dr}{(1+r)^2} - \frac{ds}{1+r}\right] \tag{26}$$

Solving for ds,

$$ds = \frac{b(1+r)\,d\overline{V}}{\overline{V}} + \frac{s dr}{1+r} - \frac{(1+r)\,dV_l}{\overline{V}} \tag{27}$$

Substituting dV_L from Eq. (25), noting that $d\overline{V} = d\overline{V}^2/2\overline{V}$, using Eq. (12), and writing for a finite increment, results in,

$$\begin{aligned}\Delta s = {} & \frac{b_m(1+r_m)\,\Delta\overline{V}^2}{2\overline{V}_m^2} + \frac{(1+r_m)\,\Delta p}{b_m \rho_{l_m} \overline{V}_m^2} + \frac{s_m \Delta r}{1+r_m} \\ & - \frac{3\rho_{g_m}|s_m| s_m C_{D_m}(1+r_m)\,\Delta x}{4 b_m \rho_{l_m} D}\end{aligned} \tag{28}$$

This is the drag equation employed when x is specified as a function of ρ.

Solving Eq. (28) for Δ x yields the required alternative equation:

$$\begin{aligned}\Delta x = \frac{4D}{3\rho_{g_m}|s_m| s_m C_{D_m}\overline{V}^2}\Bigg[\Delta p + \frac{b_m^2 \rho_{l_m}\Delta\overline{V}^2}{2} \\ + \frac{b_m \rho_{l_m}\overline{V}_m^2}{1+r_m}\left(\frac{s_m \Delta r}{1+r_m} - \Delta s\right)\Bigg]\end{aligned} \tag{29}$$

5. Heat Transfer

Although no heat is transferred to the mixture as a whole, heat transfer exists between the phases. Hence, a second energy equation must be written using as the control volume the boundary between the phases.

The work dW done on the liquid is that due to drag by the gas. (Only work done by shear or shaft forces is included in dW when writing the First Law for a control volume). Multiplying Eq. (24) by the number flow rate of drops $\dot{N} = 6\dot{m}_L/\pi D^3 \rho_L$, the drag force F_d on that quantity of liquid is

$$F_d = \frac{\dot{N}}{8} \rho_g \,|V_r|\, V_r C_D \pi D^2 = \frac{\dot{m}_l}{\rho_l} \frac{dp}{dx} + \dot{m}_l V_l \frac{dV_l}{dx} \tag{30}$$

The work done on the liquid is

$$-dW = F_d dx = \dot{m}_l \left(\frac{dp}{\rho_l} + \frac{dV_l^2}{2} \right) \tag{31}$$

The heat dQ transferred from the liquid is made up of two parts: (1) the convective cooling due to the temperature difference between the liquid and gas and (2) the evaporative cooling due to the latent heat supplied to the liquid vaporized. The convective cooling is

$$-dQ_c = hA_d \dot{N}(T_l - T_g)dt \tag{32}$$

where h is the heat-transfer coefficient, $A_d = \pi D^2$ is the surface area of a drop, and $dt = dx/V_L$ is the time required to traverse dx. Thus,

$$-dQ_c = \frac{6h\dot{m}_l(T_g - T_l)dx}{D\rho_l V_l} \tag{33}$$

The evaporative cooling is

$$-dQ_v = L_a d\dot{m}_{a_g} + L_b d\dot{m}_{b_g} \tag{34}$$

The change is enthalpy of the liquid over the pressure increment dp is

$$dH = \dot{m}_l\left(c_l dT_l + \frac{dp}{\rho_l} + \frac{dV_l^2}{2}\right) \tag{35}$$

Substituting Eqs. (31), (33), (34), and (35) into the steady-flow energy equation dQ - dW = dH, the result is

$$\frac{6h\dot{m}_l\delta T dx}{D\rho_l V_l} - L_a d\dot{m}_{a_g} - L_b d\dot{m}_{b_g} = \dot{m}_l c_l dT_l \tag{36}$$

where $\delta T = T_g - T_L$.

Writing for a finite interval, the final form of the drop heat-transfer equation is

$$\Delta T_l = \frac{1}{c_{l_m}}\left[\frac{6h\delta_m T\Delta x}{D\rho_{l_m} V_{l_m}} - L_{a_m}\frac{\Delta\dot{m}_{a_g}}{\dot{m}_{l_m}} - L_{b_m}\frac{\Delta\dot{m}_{b_g}}{\dot{m}_{l_m}}\right] \tag{37}$$

Equations (1), (17), (23), (23), and (37) are the five equations that must be solved simultaneously to obtain the values of the five dependent variables D, T_g, T_L, V_g, and V_L as a function of the independent variable p. To carry out the solution all quantities in the equations must be expressed in terms of these six variables.

C. WALL SHEAR AND BOUNDARY LAYER

For a two-phase nozzle, the momentum flux of the frictionless nozzle flow is that given by

$$\dot{M} = \dot{m}_t \overline{V}$$

The mean mixture density corresponding to the mean velocity $\overline{V}$ is

$$\rho' = \frac{\dot{m}_t}{A\overline{V}} = \frac{\rho_l}{1 + r_a} \tag{38}$$

where r_a is the ratio of gas flow area to liquid flow area $\rho_l V_l / r \rho_g V_g$.

From the definition of the momentum thickness, the value of θ at a station where the nozzle wall radius is y_o is given by

$$\dot{M} - \dot{M}_f = 2\pi y_o \theta \frac{\dot{m}_t \overline{V}}{A} = 2\pi y_o \rho' \overline{V}^2 \theta \tag{39}$$

where $\dot{M}_f$ is the momentum flux of the real flow with friction.

The skin-friction coefficient can be defined using the same quantities as single-phase flow

$$C_f = \frac{2\tau_w}{\rho'\overline{V}^2} \tag{40}$$

where τ_ω is the wall shear. It will be shown that a valid C_f value can be provided.

The boundary-layer momentum equation then becomes

$$d\theta = \frac{C_f}{2}dx - \theta\left[\frac{1 + (\delta^*/\theta)}{\overline{V}}\,d\overline{V} + \frac{1}{\rho'\overline{V}}\,d(\rho'\overline{V}) + \frac{1}{R_w}\,dR_w\right] \tag{41}$$

where δ^* is the displacement thickness, i.e., the distance the wall must be moved outward to give the same flow rate as with frictionless flow.

Assuming a $\frac{1}{7}$ power velocity profile and no density variation, the shape factor δ^*/θ is obtained from

$$\frac{\delta^*}{\theta} = \frac{\int_0^\delta [1 - (y/\delta)^{1/7}]\,dy}{\int_0^\delta (y/\delta)^{1/7}\,[1 - (y/\delta)^{1/7}]\,dy} = \frac{9}{7}$$

where δ is the velocity thickness of the boundary layer.

Noting that $d\overline{V}$ can be written $d\overline{V}^2/2V$, and that $d(\rho'\overline{V}) = d(m_t/A)$, the finite-difference form of Eq. (41) is

$$\Delta\theta = \frac{C_{f_m}}{2}\Delta x - \theta_m\left(\frac{8}{7\overline{V}_m^2}\Delta\overline{V}^2 - \frac{1}{A_m}\Delta A + \frac{1}{y_{o_m}}\Delta y_o\right)$$

Wall shear in homogeneous two-phase flow has been found to be equal to that which would exist with pure liquid at equal velocity and boundary-layer thickness, multiplied by the wetted wall fraction:

$$\tau_w = \frac{C_{f_l}}{2} \rho_l V_l^2 \frac{A_l}{A} = \frac{C_{f_l} \rho_l V_l^2}{2(1 + r_a)} \qquad (42)$$

where C_{f_1} is the skin friction coefficient for liquid at a Reynolds number of

$$R_\delta = \frac{\rho_l V_l \delta}{\mu_l}$$

For a 1/7-power profile, the velocity thickness,

$$\delta = \frac{72}{7} \theta$$

A convenient relation for C_{f_1} as a function of R_δ is the Shultz-Grunow relation which can be written

$$C_{f_l} = \frac{0.208}{(\log_{10} R_\delta + 0.425)^{2.584}}$$

Comparison of Eqs. (40) and (42) shows that C_f can be written

$$C_f = \frac{rb}{1 + r} C_{f_l}$$

Thus, the final form of the boundary-layer momentum equation is

$$\Delta\theta = \frac{r_m b_m}{1 + r_m} \frac{C_{f_l} \Delta x}{2} - \theta_m \left(\frac{8 \Delta \overline{V}^2}{7 \overline{V}_m^2} - \frac{\Delta A}{A_m} + \frac{\Delta y_o}{y_{o_m}} \right)$$

Let $\overline{V}_\delta$ be the mean velocity of the flow including the boundary layer. Then, from Eq. (39),

$$\dot{m}_t \overline{V}_\delta = \dot{M}_f = \dot{m}_t \overline{V} - 2\pi y_o \rho \overline{V}^2 \theta$$

Hence, employing Eq. (38), the mean exit velocity including the boundary layer is

$$\overline{V}_\delta = \overline{V}\left(1 - \frac{2\pi y_o \theta}{A}\right)$$

By the definition of the displacement thickness, the flow rate is reduced by the throat displacement thickness δ_t^* to

$$\dot{m}_\delta = \dot{m}_t \left(1 - \frac{2\delta_t^*}{y_{o_t}}\right)$$

D. NOZZLE THEORY SUMMARY

The preceding equations form the basis for the mathematical model which is used to predict, based on inlet conditions, the exit velocity, and temperature of the mixture. These equations also form the basis for the model which provides the optimum nozzle shape given a set of inlet conditions. Some additional relationships are, however, required. These are:

1. Phase properties - to establish the mass ratio, mass flow rate ratio of gas to liquid, and the thermal conductivity of the mixture.

2. Liquid drop drag coefficients.
3. The liquid drop heat transfer coefficients.
4. Boundary layer momentum thickness and displacement thickness.
5. Skin friction coefficient.

These five additional relationships are developed in detail in Reference [1].

III. COMPUTER PROGRAM DUAL-PHASE NOZZLE

The computer program employed in this study is based on a program developed by Dr. G. Elliott of the Jet Propulsion Laboratory in Pasadena, California. The program was updated and converted for use on the Naval Postgraduate School computer. The Dual-Phase Two-Component program employs the theory in Section II. The program is written in Fortran computer language and can be compiled using a Watfiv or Fortran IV compiler.

This program has been utilized in dual-phase nozzle analysis and to provide values for comparison with the experimental results. To use the computer program the inlet conditions have to be specified. The flow conditions are: inlet pressure; mass ratio; inlet temperature of the gas and liquid; inlet velocity of the gas and liquid; total mass flow rate; and nozzle exit pressure. Section III B, shows specified details for data input.

There are two options that can be chosen. The first is prescribed pressure-versus-distance option MOP=0. The pressure profile P(X) is selected corresponding to the adopted nozzle contour. If the pressure-versus-distance is used a P(X) input table is required. This profile is developed from the actual measured pressure values in the experiments.

(See Appendix A for sample program.) The second option consist of an optimum nozzle contour option MOP=1. This option is useful only when the liquid drop diameter is constant.

The dual-phase two-component computer program is a structured program with thirteen subroutines controlled by a main program. This arrangement improved the programming process through better organization and programming notation.

The control point of the dual-phase two-component computer program is the "main section." It controls the flow path and operation of all input data, property tables, and calculations. It accomplishes this by calling the thirteen subroutines at the appropriate times, saving wanted data in files, and printing out desired information.

One of the most important subroutines which inputs information is the "INTRP" subroutines. INTRP controls the property table inputs. It reads in four two-dimensional tables and fourteen one-dimensional tables. These inputs are the properties of the gas and liquid phases of both components of the flow in the nozzle. The subroutine writes the values of these tables into a file and retrieves appropriate values from that file. INTRP can also interpolate for values used throughout the entire program.

Input of case data is controlled by subroutine "Sect 1." Identification information and case heading information is read and printed for each instance. Sect 1 also places the pressure vs. distance profile, if specified, in an array.

"Sect 2" through "Sect 6" are the subroutines which calculates the flow data. Sect 2 sets the initial conditions indicated in the input, and begins the iterations. Sect 3 computes initial flow rates of both components; the initial area of the nozzle; slip velocity; mean free stream velocity; and slip friction. Sect 4 computes the changes in flow parameters and new distances. It then begins to calculate new conditions such as flow rate, temperature, velocities, surface tension and mean area. Sect 5 is the binary cut convergence routine and computes mean boundary-layer parameters.

If a problem is diagnosed in any subroutines and "diagno" is called, it will print all output parameters calculated to that point. It also does the same if there is a convergence problem.

There are two subroutines that output calculated data, subroutine "Write" and subroutine "Output." Subroutine "Write" will send output information to the printer for a hard paper copy. Subroutine "Output" reads and stores the output on a file.

The two-phase two-component program has been written with comment statements in the text of the program. These will allow for a more understandable and, therefore, a more easily modified program. For specific details on the content of these subroutines, see Appendix M.

The dual-phase nozzle program was tested for correct output. Sample data and results were obtained from

Dr. David Elliott, were inputted into the program, and executed. The output was compared to the sample data. The program produced duplicate results.

The program begins by storing fluid property tables and reading in all input data. All nozzle inlet conditions are computed. The program then proceeds half a pressure step at a time. At the middle of each pressure interval, the changes in quantities across the interval are computed using the properties interpolated from the table for that pressure, and for the existing temperature. The change in slip is found if the pressure profile P(X) is specified. At the end of each pressure step, the flow conditions are updated and initial conditions are determined for the next step. The dropsize is reduced at the point when the Weber number exceeds six. The flow conditions are printed if the pressure is one selected for output. The computation continues until the last pressure step has been completed and flow conditions at the smallest flow area encountered are printed as the throat conditions.

A. PROPERTY TABLES

1. Heat capacity of component "A" vapor in BTU/LBM-R is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 heat capacity (BTU/LBM-R)

25-36 pressure (psi)

37-48 heat capacity (BTU/LBM-R)

49-60 pressure (psi)

61-72 heat capacity (BTU/LBM-R)

The maximum entries of temperature are 35 values. For each value of temperature, the maximum number of entries of pressure and heat capacities are 35 values. Each row of this table will be terminated with the pressure and heat capacity equal to 10^5. These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix B can be used to determine the values of heat capacities. The program structures its output in the format needed for the table input. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 heat capacity at .01 P

15-21 heat capacity at .4 Pa

22-28 heat capacity at .7 Pa

29-35 heat capacity at 1.0 Pa

34-42 heat capacity at 4.0 Pa

43-49 heat capacity at 7.0 Pa

50-56 heat capacity at 10.0 Pa

57-63 heat capacity at 40.0 Pa

64-70 heat capacity at 70.0 Pa

The temperature must be entered with increasing value.

2. Heat capacity of component "B" gas, BTU/LBM-R is a function of temperature and pressure. This two-dimensional table has the same format as part A1 above.

3. Molecular weight of component "A" vapor is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 molecular weight

25-36 pressure (psi)

37-48 molecular weight

49-60 pressure (psi)

61-72 molecular weight

The maximum number entries of temperature are 35 values. For each value of temperature, the maximum entries of pressure and molecular weight are 35 values. Each row of this table will be terminated with the pressure and molecular weight equal to 10^5. These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix C can be used to determine the values of molecular weight. The program formats its output in the format needed for the table input of the two-component two-phase computer program. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. The program used in Figure 8 can only be used with ideal gases. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 density at .01 P

15-21 density at .4 Pa

22-28 density at .7 Pa

29-35 density at 1.0 Pa

34-42 density at 4.0 Pa

43-49 density at 7.0 Pa

50-56 density at 10.1 Pa

57-63 density at 40.0 Pa

64-70 density at 70.0 Pa

The temperatures must be entered with increasing value.

4. Molecular weight of component "B" gas is a function of temperature and pressure. This two-dimensional table has the same format as part A3 above.

5. There are fourteen one-dimensional tables. The one-dimensional tables are entered in the following format (for Z(T)):

Card 1: (format 6E12.6)

cols.

1-12 Ti-2, oR

13-24 Ti-2

25-36 Ti-1 $2 \leq i \leq 50$

37-48 Zi-01

49-60 Ti

61-72 Zi and Tj-1 < Tj for $2 \leq j \leq 50$

Each table is terminated by two consecutive entries of 10^5, i.e., Tk ≡ Zk ≡ 10^5 (1.0E5 right adjusted in the field). The fourteen one-dimensional tables are (in order requested):

1. CAL(T) heat capacity of component A liquid, BTU/LBM oR
2. CBL(T) heat capacity of component B liquid, BTU/LBM oR
3. LA(T) latent heat of vaporization for component A, BTU/LBM
4. LB(T) latent heat of vaporization for component B, BTU/LBM
5. PBO(T) vapor pressure of component B
6. ROAL(T) density of liquid component A, LBM/FT3
7. ROBL(T) density of liquid component B, LBM/FT3
8. KAG(T) thermal conductivity of component A gas, BTU/FT HR oR
9. KBG(T) thermal conductivity of component B gas, BTU/FT HR oR

10. VIAL(T) viscosity of liquid component A, LBM/FT HR

11. VIBL(T) viscosity of liquid component B, LBM/FT HR

12. VIAG(T) viscosity of gas component A, LBM/FT HR

13. VIBG(T) viscosity of gas component B, LBM/FT HR

14. SIG(T) surface tension of liquid component B, DYNE/CM

Appendix D gives sample property table for input.

B. CASE INPUT

A blank card must separate the property table from the data set decks following.

Card 1: (format 4A4, A2, 3A4, 7A4, A32, 2I6)

cols.

1-18 date

19-30 case number, may be any alphanumeric data

31-60 identification

61-66 NS, number of pressure steps per printout (right justified integer).* Use -1 if new property tables follows.

57-72 NP, number of printouts (right justified)

Card 2: (All integers right justified in field)

(format 11I6)

cols.

1-6 MBU, =0 constant droplet size, =1 drop breakup

7-12 MOP, =0 X(P) table to be supplied, =1 X(P) is to be optimized

13-18 MGEO, =0 circular, =1 annular

19-24 NDS, maximum number of S iterations

25-30 NSO, maximum number of So iterations

31-36 NB, maximum number of TB iterations

37-42 NNS, first setting of step counter

Card 3: (format 5E12.6)

cols.

1-12 DP, pressure step size, negative for decreasing, psi

13-24 RC, mass flow ratio

25-36 PHI, angle of annular nozzle axis, deg

37-48 RAXO, annular nozzle axis, in.

49-60 EMT, total flow rate *P final = PO + (NS*NP-NNS-1)*DP+DP1

Card 4: (format 6E12.6)

cols.

1-12 H, inverse Henry's Law constant, psi

13-24 ALAM, Lagrangian multiplier

25-26 DPL, first pressure step size

37-48 WAL, molecular weight of liquid a

49-60 WBL, molecular weight of liquid b

61-72 SA, Sutherland constant for component A, oR

Card 5: (format 6E12.6)

cols.

1-12 SB, Sutherland constant for component B, oR

13-24 DO, initial drop diameter, in.

25-36 PO, initial pressure, psia

37-48 TGO, initial gas temperature, oR

49-60 TLO, initial liquid tempeature, oR

61-72 VGO, initial gas velocity, FT/S

Card 6: (format 6E12.6)

cols.

1-12 VLO, Initial liquid velocity, FT/S

13-24 THOO, initial momentum thickness of outer wall boundary layer, in.

25-36 THIO, initial momentum thickness of inner wall boundary layer, in.

37-48 EDS, convergence criterion for S

49-60 ESO, convergence criterion for So

61-72 EB, convergence criterion for T, oR

If MOP=0, the following cards are present: in 10 Card 7: (format 7A4, A2) cols.

1-30 X(P) table identification (and alphanumeric data).

Card 8: (format 6E12.6)

cols.

1-12 pressure, pi-2, psia

13-24 distance, xi-2, in.

25-36 pressure, pi-1 $3 \leq i \leq 75$

37-48 distance, xi-1

49-60 pressure, pi

61-72 distance, xi

The last two entries are 1.0E5 and 1.0E5 right adjusted in their fields. The table must be monotonic increasing or decreasing. New property tables may be used by putting -1 in cols. 61-66 of Card 1, and following this with new property tables and data sets. Appendix E is a sample input data.

C. OUTPUT

For each case, the case identification is printed followed by the input parameters. If MOP=0, the X(P) table forms a part of this output. The following output then appears.

1. X distance, in.
2. P pressure, psia
3. R mass flow ratio
4. vb mean free-stream velocity, ft/s
5. a flow area, in. 2

6. tb gas temperature, or

7. tl liquid temperature, or

8. vg gas velocity, ft/s

9. vl liquid velocity, ft/s

10. vs slip velocity vg-vl, ft/s

11. s slip fraction vs/vb

12. d drop diameter, in.

13. rv ratio of gas volume flow to liquid volume flow

14. ra ratio of gas flow area to liquid flow area

15. alpha mass fraction of component a dissolved in liquid

16. beta mass fraction of component b vapor in gas

17. mg gas flow rate, lbm/s

18. ml liquid flow rate, lbm/s

19. rog gas density, lbm/ft3

20. rol liquid density, lbm/ft3

21. wag molecular weight of component a gas

22. wbg molecular weight of component b gas

23. wg mean molecular weight of gas

24. pa partial pressure of component a, psia

25. pb partial pressure of component b, psia

26. la latent heat of vaporization of component a, btu/lbm

27. lb latent heat of vaporization of component b, btu/lbm

28. sigma liquid surface tension, dyne/cm

29. cgm specific heat of gas (at midpoint of pressure step), btu/lbm of

30. clm specific heat of liquid, btu/lbm of

31. vigm viscosity of liquid, lbm/ft hr

32. vilm viscosity of gas, lbm/ft hr

33. kgm thermal conductivity of gas, btu/hr ft of

34. rem reynolds number of flow over drops

35. cdm drag coefficient of drops

36. hm heat transfer coefficient of drops, btu/hr ft2

37. rb mass flow ratio after velocity and temperature equalization

38. ab flow area after equalization, in. 2

39. tb temperature after equalization, or

40. rvb volume flow ratio after equalization

41. alphb alpha after equalization

42. betab beta after equalization

43. mgb gas flow rate after equalization, lbm/s

44. mlb liquid flow rate after equalization, lbm/s

45. vilb liquid viscosity after equalization, lbm/ft hr

46. rogb gas density after equalization, lbm/ft3

47. rolb liquid density after equalization, lbm/ft3

48. wagb molecular weight of component a gas after equalization

49. wbgb molecular weight of component b gas after equalization

50. wgb mean molecular weight of gas after equalization

51. pab partial pressure of component a gas after equalization, psia

52. pbb partial pressure of component b gas after equalization, psia

53. g separator friction parameter

54. ref separator film reynolds number

55. yo distance from nozzle axis to outer wall, in.

56. wom angle of outer wall relative to axis, deg

57. tho momentum thickness of outer boundary layer, in.

58. delo velocity thickness of outer boundary layer, in.

59. delso displacement thickness of outer boundary layer, in.

60. redom reynolds number of outer boundary layer

61. cfom skin friction coefficient of outer boundary layer

62. twom shear stress on outer wall, psi

63. vbd mean velocity including boundary layer, ft/s

64. wim angle of inner wall relative to axis, deg

65. thi momentum thickness of inner boundary layer, in.

66. deli velocity thickness of inner boundary layer, in.

67. delsi displacement thickness of inner boundary layer, in.

68. redim reynolds number of inner boundary layer

69. cfim skin friction coefficient of inner boundary layer

70. twin shear stress on inner wall, psi

71. nna number of iterations required to optimize X(P)

72. nis number of iterations required to converge cn s or so

73. nib number of iterations required to converge on tb

IV. EXPERIMENTAL SYSTEM

The experimental system can be grouped into three subsystems. These are:

a) nozzle

b) air supply system

c) liquid injection system

Each subsystem is described in the following sections. Figure 11 is an overall system schematic.

A. NOZZLE

The nozzle has a convergent-divergent flow passage. It is 12 inches long with a variable exit area. The exit area can be varied from .45313 square inches to .84375 square inches. The pivot point is located 1 inch above the throat. This causes the throat to vary when the exit is varied. Since the change in the throat is negligible, it will be considered to be constant. It has a throat area of .45 square inches. The inlet area is 1.625 square inches. The throat is located 4 inches from the inlet. The nozzle is constructed by sandwiching two 1/2 inche thick machined aluminum nozzle profile plates between 1/2 inch plexiglas plates (Fig. 12). The aluminum nozzle plates are located at the end of a 30 inch long entry section and are easily adjustable. Figure 13 shows a close up of the aluminum section of the nozzle.

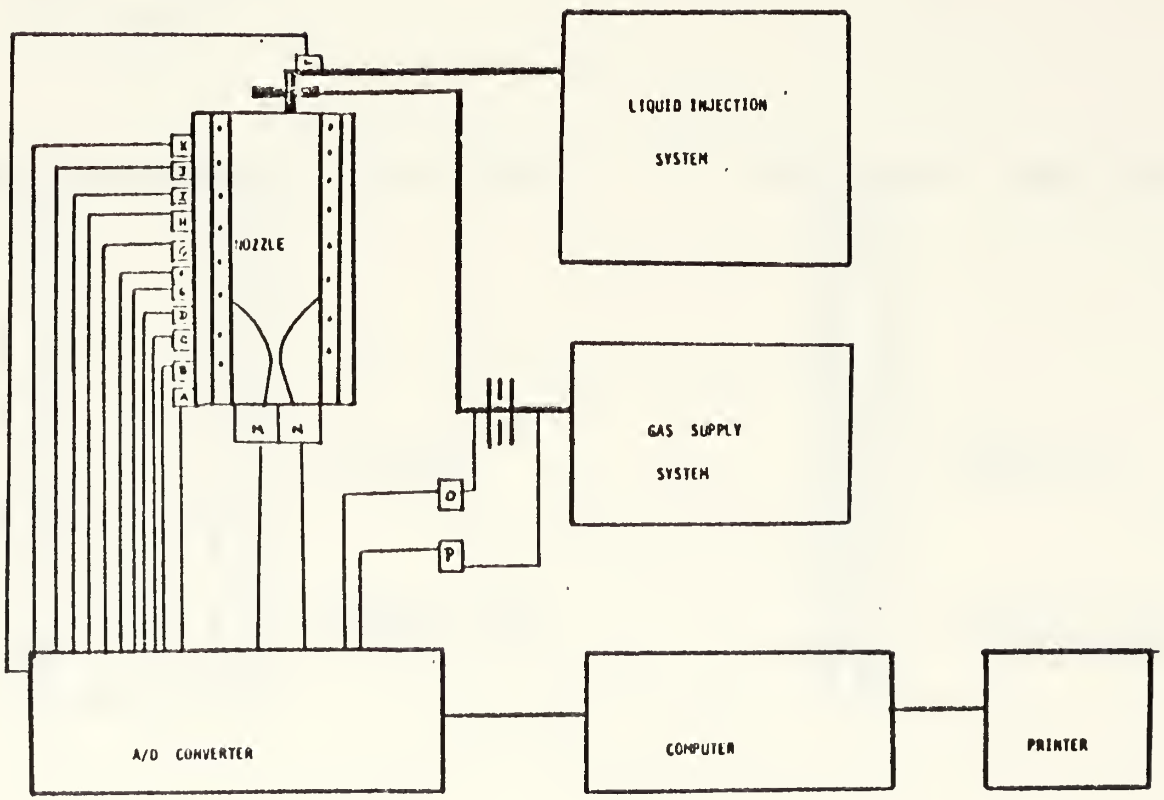


Figure 11. Experimental System Schematic

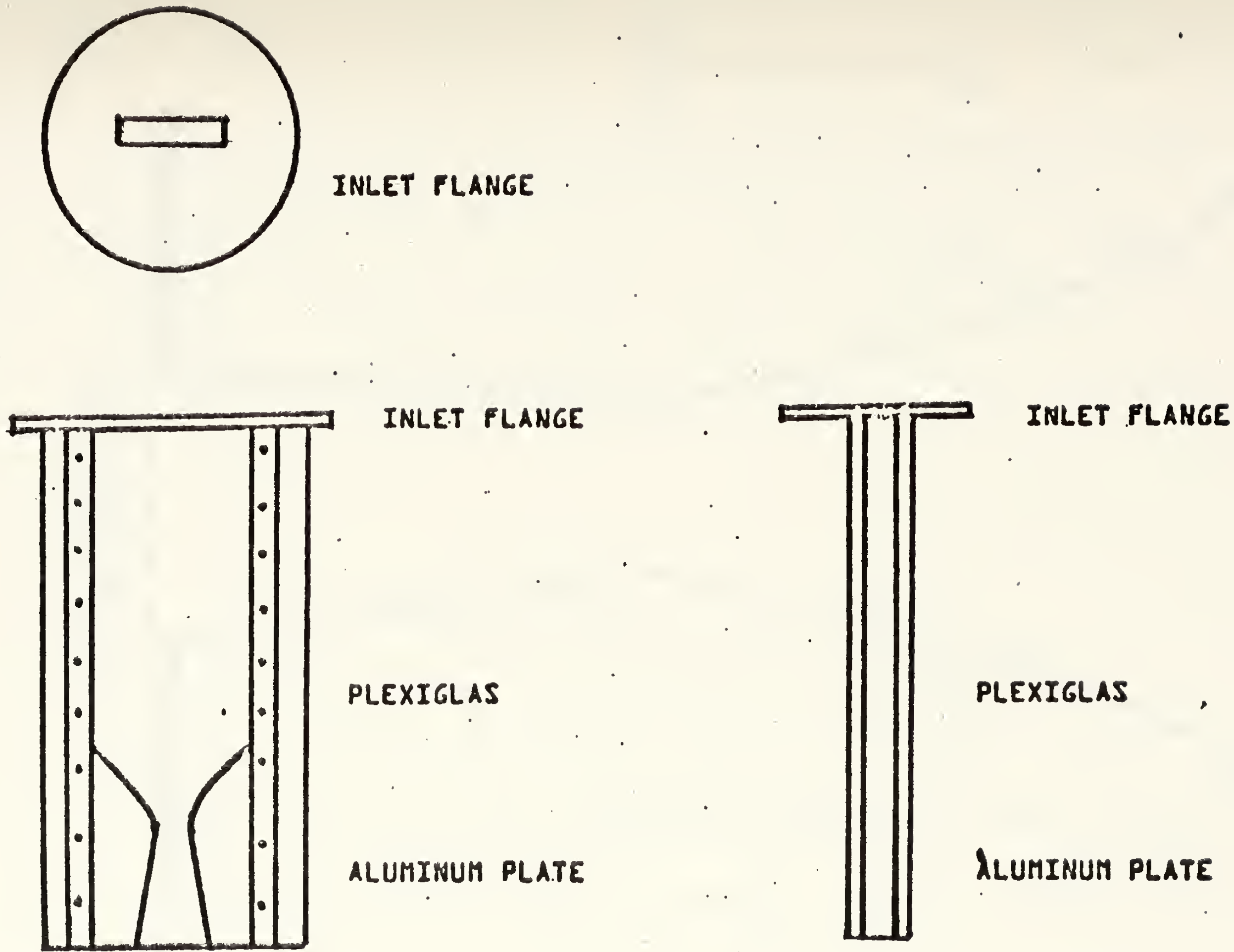


Figure 12. Nozzle Assembly Drawing

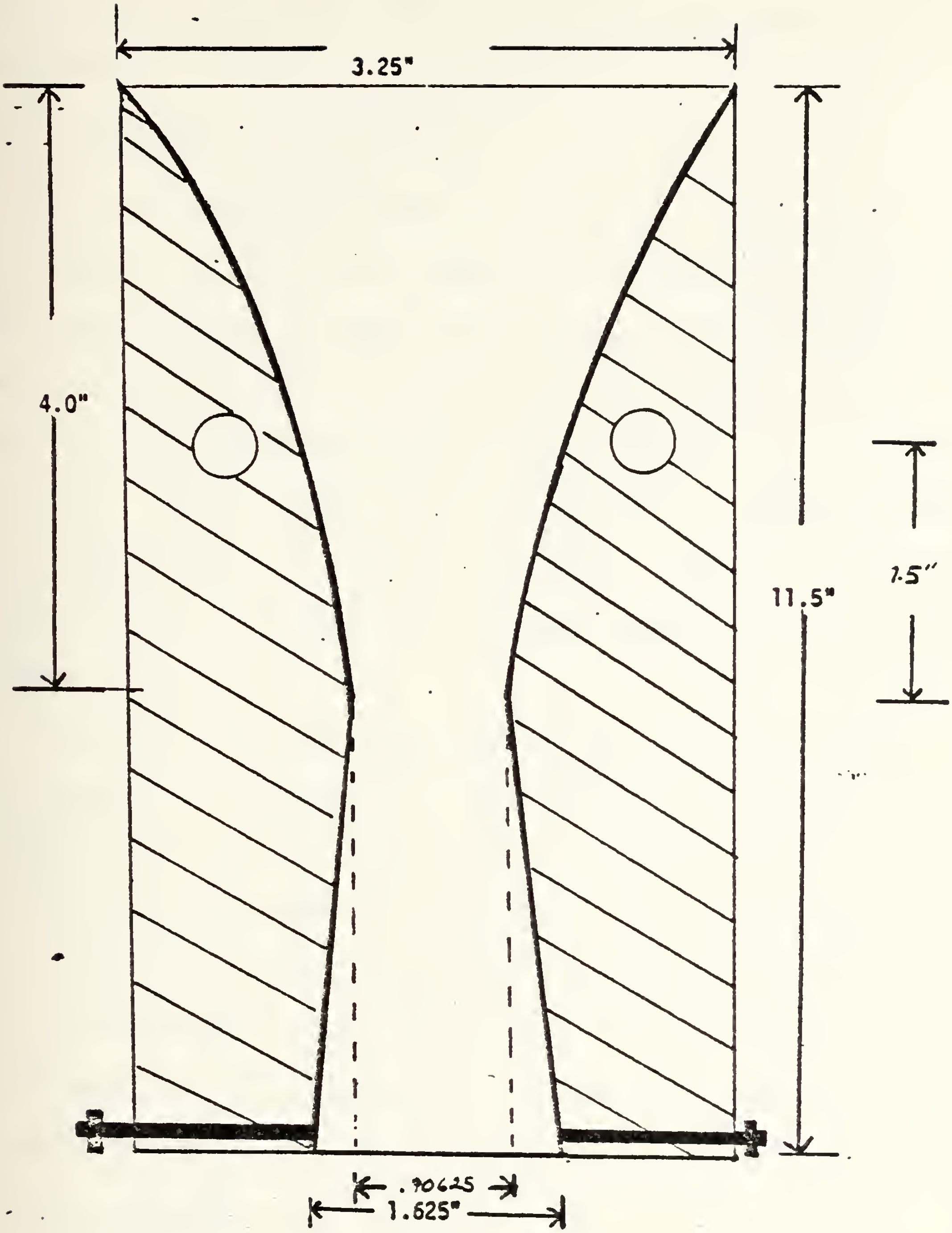


Figure 13. Nozzle Geometry Schematic

The inlet section provides the necessary space for pressure taps, liquid injection tubes, and other instrumentation and configuration options.

B. AIR SYSTEM

The air system is shown in Figure 14. Two 117 cubic feet tanks supplied with compressed air from an Ingersol Rand two-stage air compressor provides the air storage volume required to support the nozzle's operation. Each storage tank has a pneumatically control Norgren gate valve at its exit. These valves are operated by a nitrogen actuator and controlled by a pressure regulator. The nitrogen is regulated to 40 psi control pressure which will open the Norgren valve.

The nozzle is supplied with air via a 3" i.d. pipe. The air supply to the nozzle is controlled by a solenoid actuated nitrogen operated 3 inch ball valve. The nitrogen is supplied via a regulator. By varying the nitrogen supply pressure to the ball valve, supply air pressure to the nozzle can be controlled. Air flow to the nozzle is measured with a standard ASME orifice plate. Figure 15 shows the dimensions of the orifice. The orifice is a model D-10512 with a 0.920 inch bore.

C. LIQUID INJECTION SYSTEM

The liquid injection system, Figure 16, is supplied by house water and is further pressurized by an Aurora electric

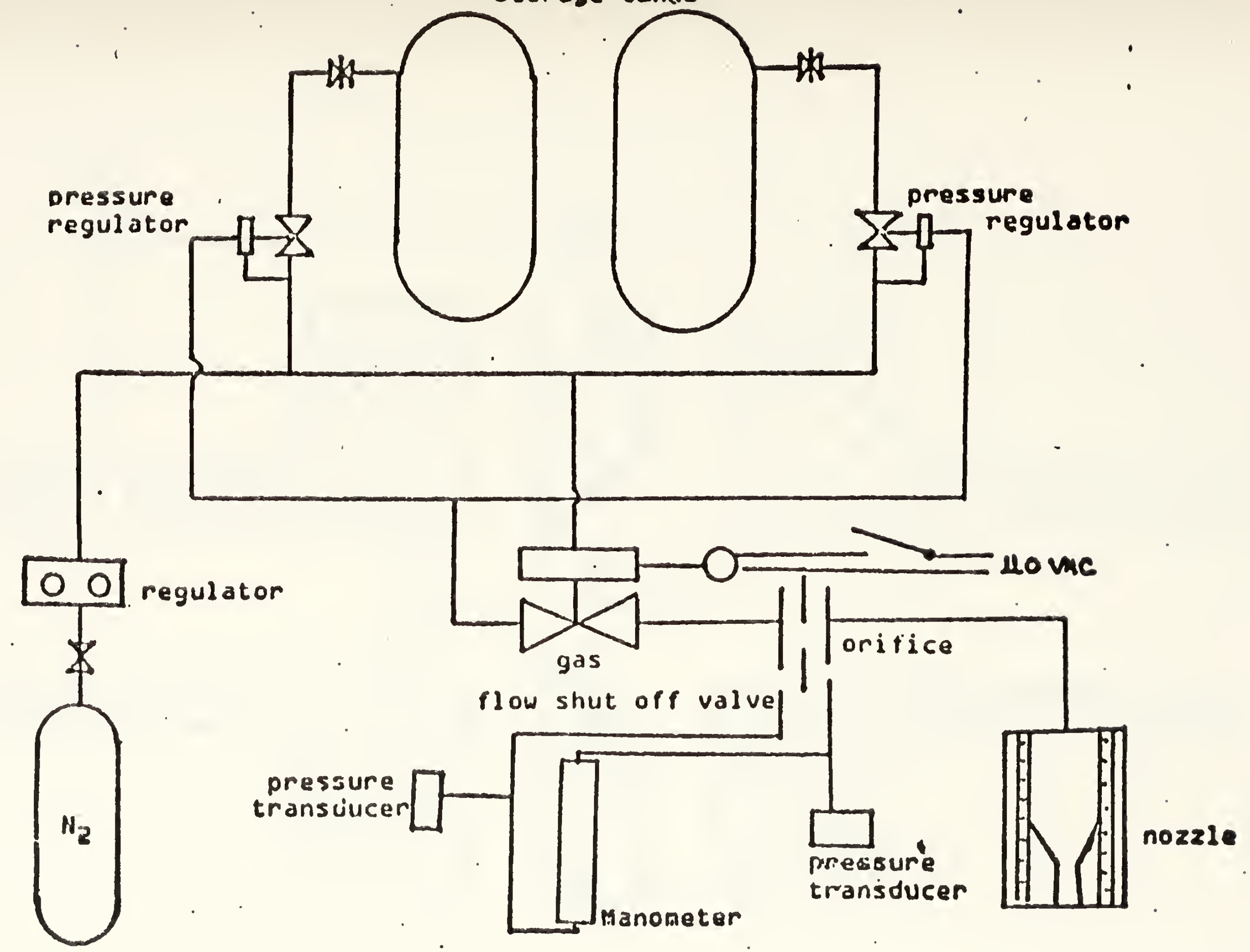


Figure 14. Orifice Schematic

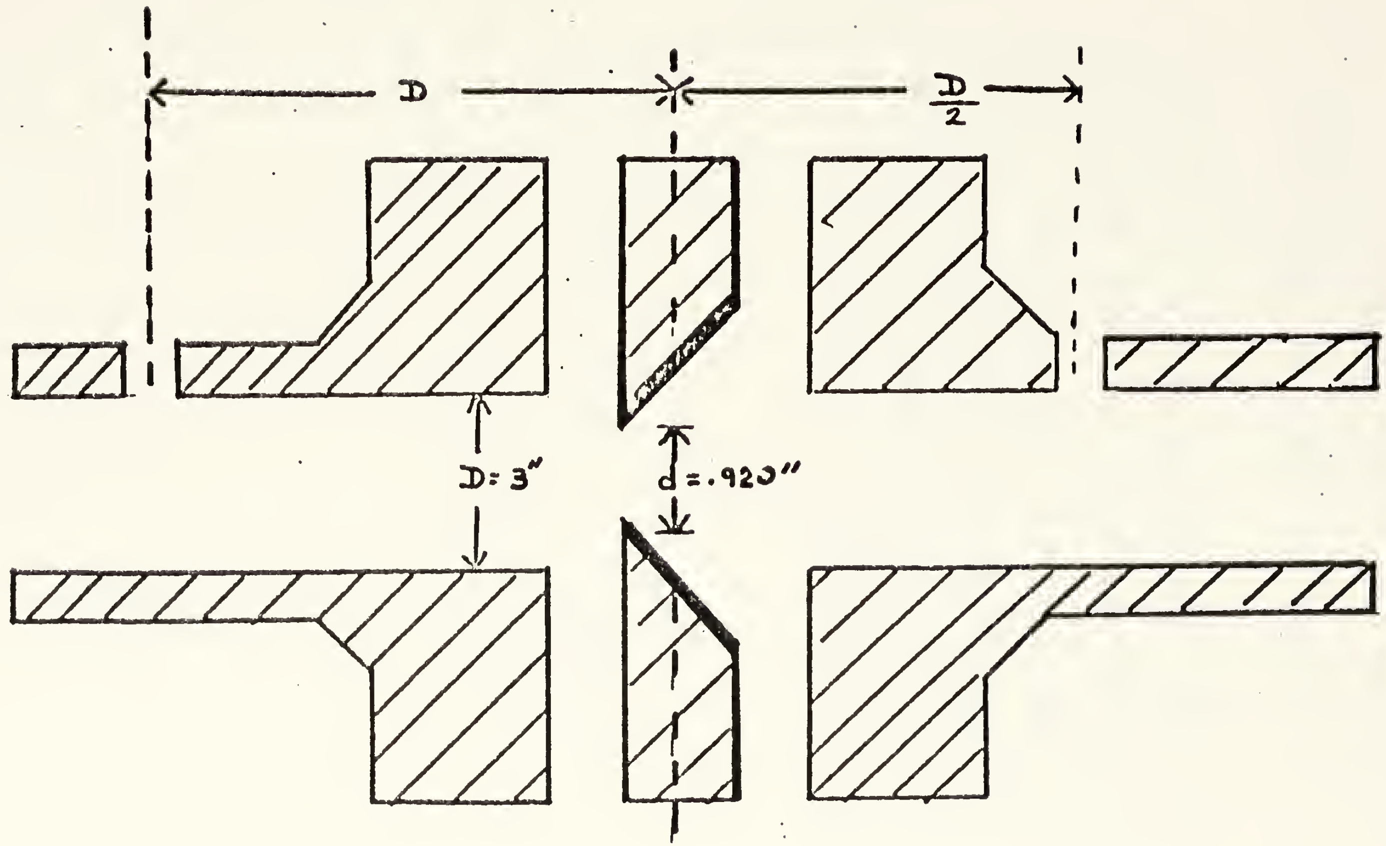


Figure 15. Air System Schematic

pump model/type 317696. The pump is rated at 50 gallons per min. The pump supplies pressurized water to the injection tube via two flowmeters (rotometers). The flowmeters are F&P co. precision bore flowrator tubes. One rotometer is rated at 1 to 12 gallons per min. and the other at .6 gallons per min.

The liquid injector is a 0.25 inch brass tube inserted in the 3" i.d. air supply pipe just upstream of the flange connection to the test section. The injector tube is drilled with sixteen 1/16th inch diameter holes facing the test section entrance. The drilled holes were made as small as possible consistent with achieving a significant liquid mass flow rate.

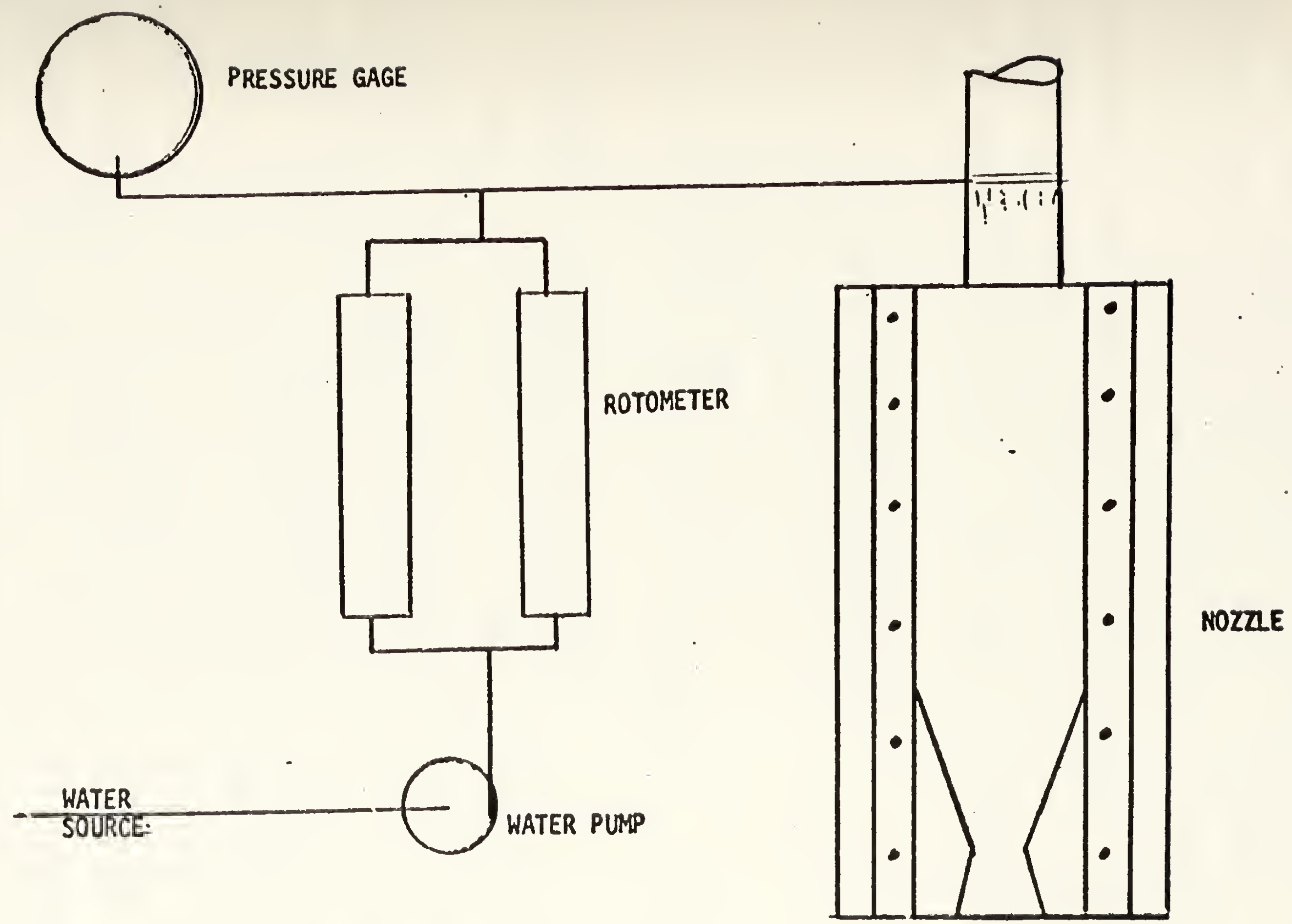


Figure 16. Liquid Injection System Schematic

V. INSTRUMENTATION SYSTEM

The instrumentation system is designed for automated data acquisition, analysis, and display. A schematic is depicted in Figure 17. Where ever possible, test operations and sequencing are under direct computer control. Each parameter measured involves an appropriate transducer, excitation source, and calibration procedure. The major instrumentation subsystems are:

(A) Pressure Measuring Transducers

(B) Nozzle Thrust Force Block

(C) Flow Measurement Devices

(D) Data Acquisition/Control System

A. PRESSURE MEASURING TRANSDUCERS

Pressure measurements are made in fourteen locations throughout the experimental apparatus. Eleven Micro Switch 140PC pressure transducers model PK 87633 are placed on the nozzle assembly to measure pressure at various axial positions. Specifications for this model transducer are shown in Figure 18. The first pressure tap is located at one half inch from the inlet along the axis of the nozzle. The remainder are placed at one inch intervals toward the nozzle exit. These pressure taps are connected to the pressure transducers via a 1/4" o.d. plastic tubing. The

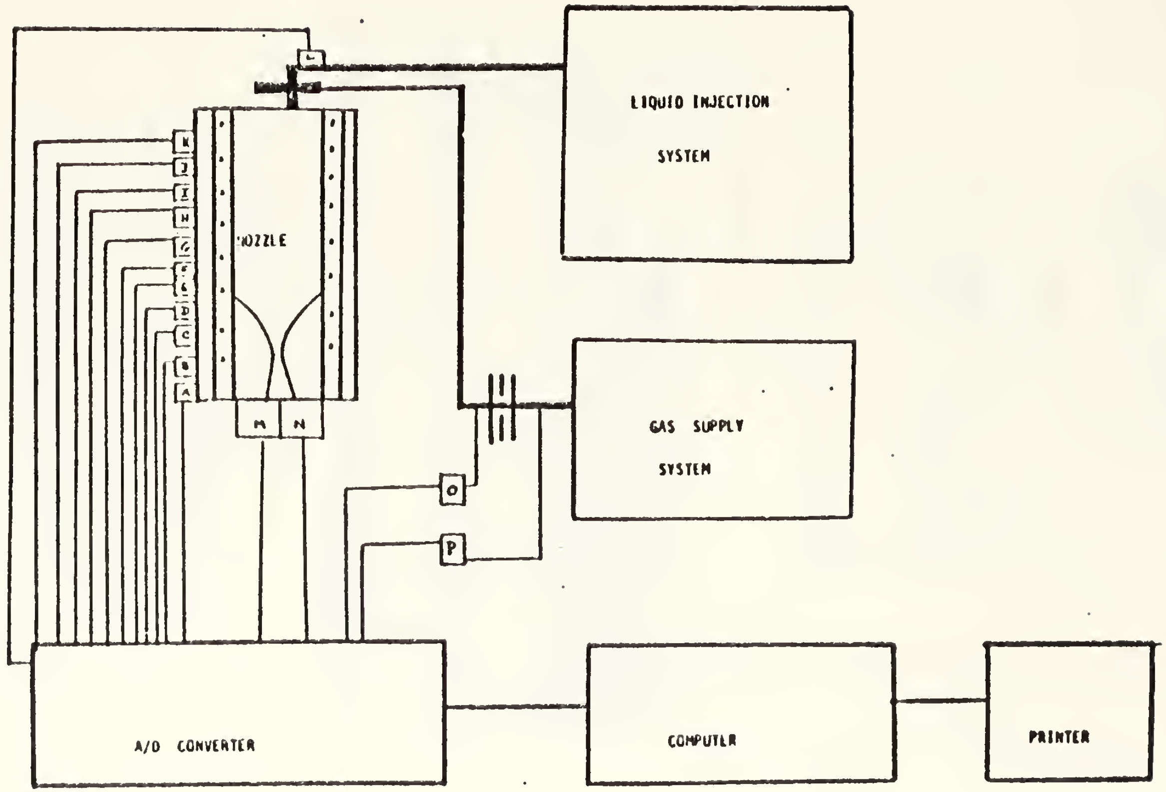
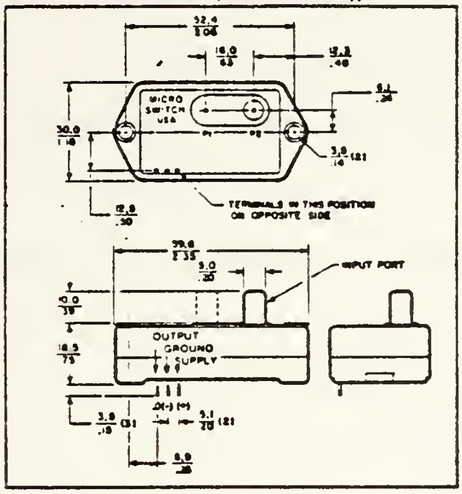


Figure 17. Instrumentation System Schematic

MOUNTING DIMENSIONS (for reference only)

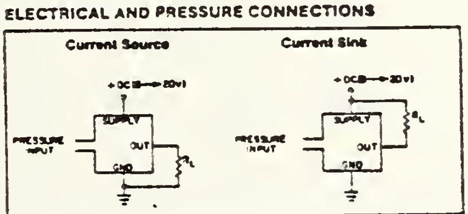


140PC SPECIFICATIONS at 8.0 0.01VDC, 25°C

ALL LISTINGS

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.85	5.00	5.15	Volts
Null Offset	All	0.95	1.00	1.05	Volts
Excitation	All	8.00		20.0	VDC
Output Current	All				
Source		10.0			mA
Sink		5.0			
Supply Current	All				
(10K ohm load)			8.0		mA
Overpressure	0-1			20	psi
	0-5			20	
	0-15			45	
	0-15/0-30(L)			50	
Operating Temperature	-55°C to +125°C(-65°F to +257°F)				

ELECTRICAL AND PRESSURE CONNECTIONS



WARNING: Damage may result from reversal of supply and ground connections.

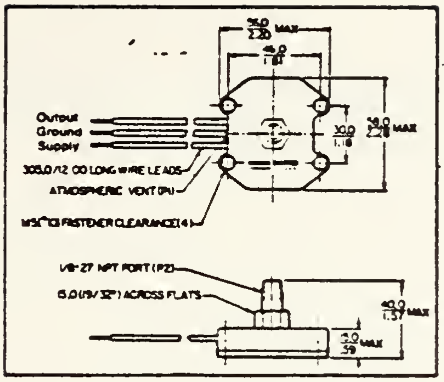
Figure 18. 140PC Pressure Transducer Specifications

pressure transducers are mounted on the side panel of the nozzle. See Figure 19 for locations. Each transducer has an identification letter corresponding to its position. Table I is the ID code for the transducers.

At the nozzle inlet a Micro Switch 200PC pressure transducer model PK 87690 is placedin the inlet line to measure the dual-phase mixture inlet pressure. Specifications for this model transducers are shown in Figure 19. Gas supply pressure is measured using a 200PC pressure transducer located at the orifice outlet. This transducer is also used to help measure differential pressure across the orifice. Another 200PC transducer is placed at the inlet of the orifice. The data acquisition program calculates the orifice differential pressure and then the air mass rate using the output from the above two transducers.

The pressure transducers provide output voltage proportional to applied pressure. These operate from a single, positive supply voltage ranging from 8 to 20 VDC. The supply voltage was maintained at 15VDC.

Each pressure transducer sends back a signal proportional to the input pressure. The signal is converted in the A/D converter to a digital signal which can be read by the HP9826. The pressure transducers were calibrated using a known pressure source. Appendix F depicts a sample calibration program written for a HP9826 computer. This program reads ten



200PC SPECIFICATIONS at 8.0 ± 0.01VDC, 25° C (unless otherwise noted)

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.80	5.00	5.20	V
Null Offset	All	0.95	1.00	1.05	V
Proof Pressure ①	0-100			200	psi
	0-250			500	
Burst Pressure ②	0-100		800		psi
	0-250		1000		
Excitation	All	8.0		20.0	VDC
Output Current Source Sink	All	 10.0 5.0			mA
Supply Current	All		8.0		mA
Opereting Tempature	All	-55° C to +125° C (-65° F to +257° F)			

*F.S.O. is the algebraic difference between end points (null and full pressure outputs).

① Maximum pressure without damage
② Without housing envelope rupture.

ELECTRICAL AND PRESSURE CONNECTIONS

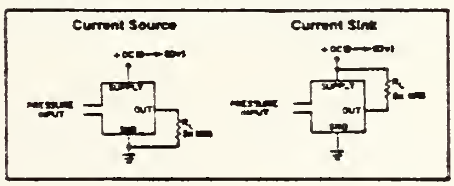


Figure 19. 200PC Pressure Transducer Specifications

Table I. ID Code for Instrumentation

Letter Designation	Description
A	10.5" from inlet
B	9.5" from inlet
C	8.5" from inlet
D	7.5" from inlet
E	6.5" from inlet
F	5.5" from inlet
G	4.5" from inlet
H	3.5" from inlet
I	2.5" from inlet
J	1.5" from inlet
K	0.5" from inlet
L	inlet nozzle pressure
M	force-block signal
N	force-block excitation voltage
O	orifice exit pressure
P	orifice inlet pressure

$$\text{Pressure} = A + B(\text{volts}) + C(\text{volts})^2 + D(\text{volts})^3$$

pressure transducer	A	B	C	D
A	-6.049	3.926	-.17336	.01121
B	-7.059	4.234	-.22921	.01415
C	-.6491	3.934	-.16025	.00945
D	-7.056	4.692	-.34118	.01898
E	-7.009	4.152	-.20717	.01237
F	-6.389	3.933	-.16055	.00951
G	-6.589	3.956	-.16427	.00961
H	-6.588	3.908	-.15806	.00942
I	-6.595	3.949	-.16270	.00957
J	-6.353	3.927	-.16509	.00998
K	-6.203	3.846	-.14697	.00880
L	-20.207	11.157	-.08591	.00492
O	-20.668	11.068	-.07562	.01118
P	-18.827	11.928	-.17715	.01101

Figure 20. List of Polynomial Coefficients for Pressure Transducer

values of pressure for each 140PC transducer and gives the mean and standard deviation for each from 0 to 45 psi in 5 psi increments. Appendix G depicts sample output of the program for a given pressure. Appendix H illustrates the program used to calibrate the 200PC pressure transducers. The program works as above, except values are taken from 0 to 60 psi at 5 psi increments.

Data obtained during calibration source pressure is plotted for each pressure transducer (Appendix I). Each plot was curve fitted with a third order polynomial. Figure 20 shows coefficients of the polynomial. These polynomials are used in the data acquisition/control program to convert transducer readings to pressure readings.

B. NOZZLE THRUST FORCE-BLOCK

The thrust produced by the nozzle was employed to deduce the nozzle exit velocities. The thrust was measured by instrumenting a target plate in the exit flow field. Appropriate screens were installed to prevent liquid "bounce back." The jet momentum force on the target is acquired by a balance beam system shown in Figure 21. A Kistler-Morse force block provides an analog signal proportional to the nozzle jet momentum.

The calibration of the force-block was completed by placing known weights on the force-block side of the balance

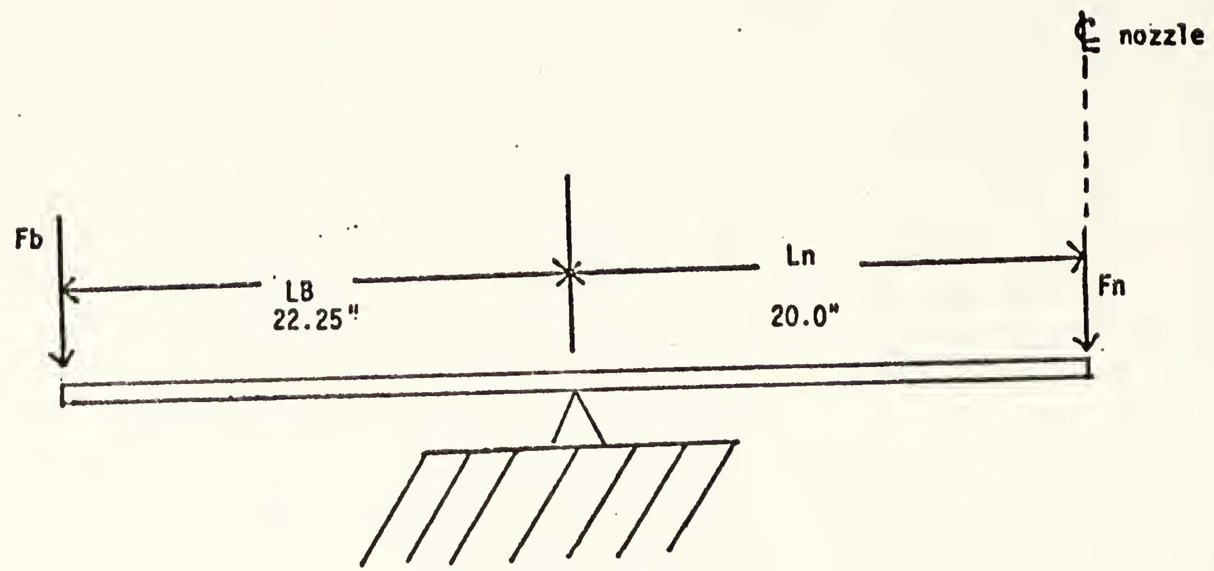


Figure 21. Force-Block Balance Beam Diagram

beam, (Figure 21), and recording the voltage produced. Appendix J shows results of this calibration. These results were curve fitted with a third order polynomial. The following is the volt-to-force conversion polynomial:

FB = (1/453.6)*(-234.396+48715.28*VOLTS-11261.54*VOLTS+33899.3*VOLTS)

FN = FB*LB/LN

FN = FORCE AT NOZZLE EXIT (LBF)

FB = FORCE AT FORCE BLOCK (LBS)

LB = LENGTH FROM PIVOT TO FORCE BLOCK(IN.)

LN = LENGTH FROM PIVOT TO DIRECTIONAL OBSTRUCTION(IN.)

C. FLOW MEASUREMENT

1. Air mass flow measurement for the system achieved by measuring the inlet and outlet pressure on a D-10512 orifice with a 0.92 inch bore. For details on orifice see Section III. Air flow is calculated in the data acquisition program. The program uses the following equation obtained from References 4 and 5.

$$M_{air} = K\, A_2\, Y\sqrt{2G_c \quad \rho_1 (P1-P2)} \qquad \text{where}$$

$K = CE$

$E = {}^{1}/(1-B^4)^{1/2}$

$\beta = d/D$

$C = 0.60$

$A_2 = \text{AREA OF ORIFICE} = \frac{\pi D^2}{4}$ FT2

G_c = 32.2 FT/SEC2

ρ_1 = DENSITY LBM/FT3

P1 = PRESSURE AT INLET IN LBF/FT2

P2 = PRESSURE AT LUTLET IN LBF/FT2

M_{air} = AIR MASS FLOW RATE LBM/SEC

The discharge coefficient C is the factor that accounts for losses through the orifice. Since the values of C varies from .62 to .60 for R_d number from 10^4 to 10^7 with β = .3, C will be considered constant.

2. Water flow measurement was made using two rotometers. Calibration of the rotometers were made by measuring the time for a given weight of fluid flow. The mass flow rate was calculated and plotted versus the rotometer reading. Appendix K is the plot of the results. The plot was curve fitted with a third order polynomial. The following is that polynomial:

$MH20 = -.0063268+.002097278*RR-.00000658*RR^2+1.1X10*RR^2$

where RR = rotometer reading

D. DATA ACQUISITION/CONTROL SYSTEM

The heart of the data acquisition system is a HP9826 small computer. The HP9826 communicates via a Hewlett Packard 3497A data acquisition/control system. This system gathers data from the pressure transducers and nozzle thrust force-block. It converts the analog signal to digital data, and stores the data in memory. Figure 22 shows a pressure transducer to A/D converter channel connection, and Figure 23

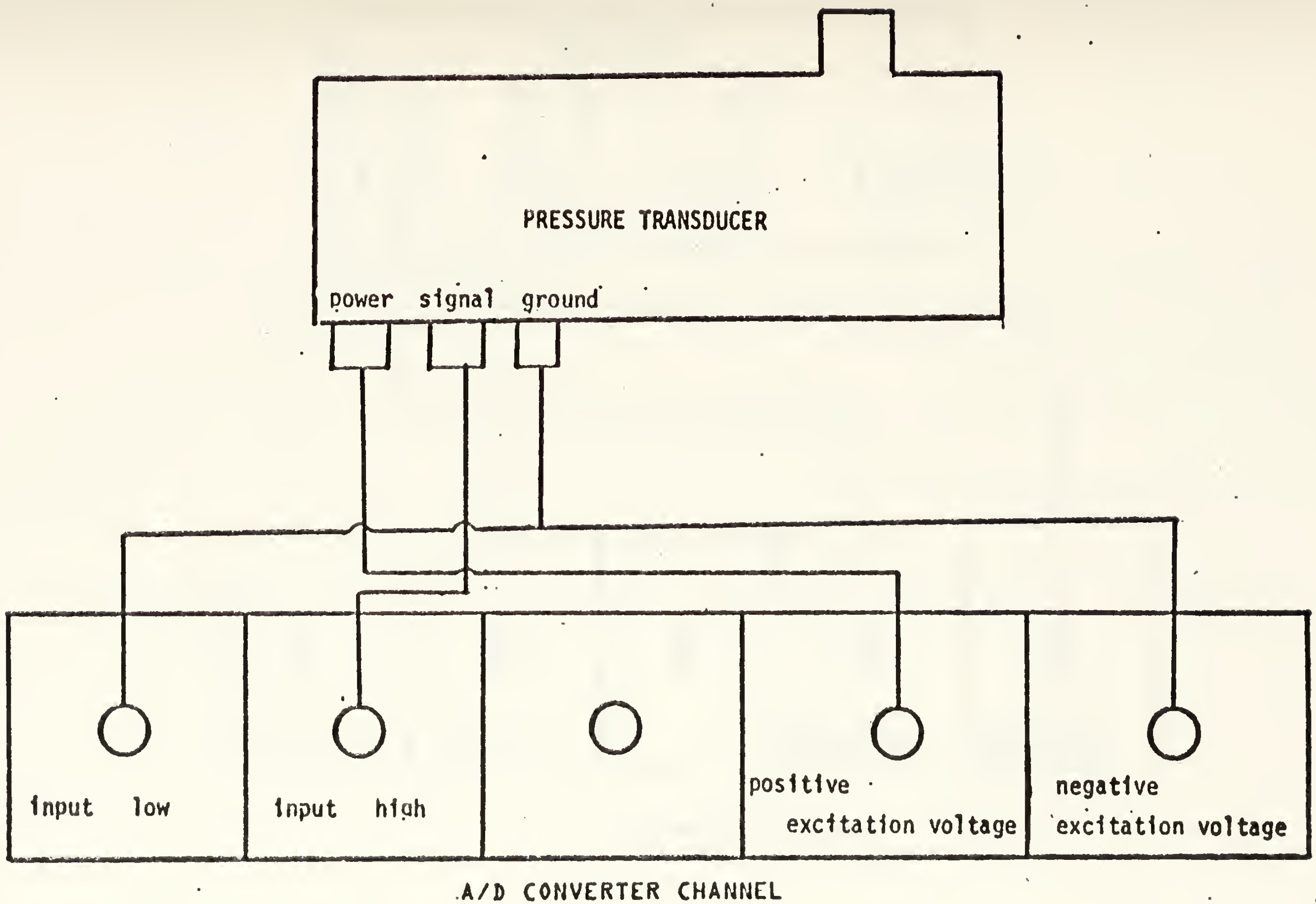


Figure 22. Transducer-to-Channel Connection

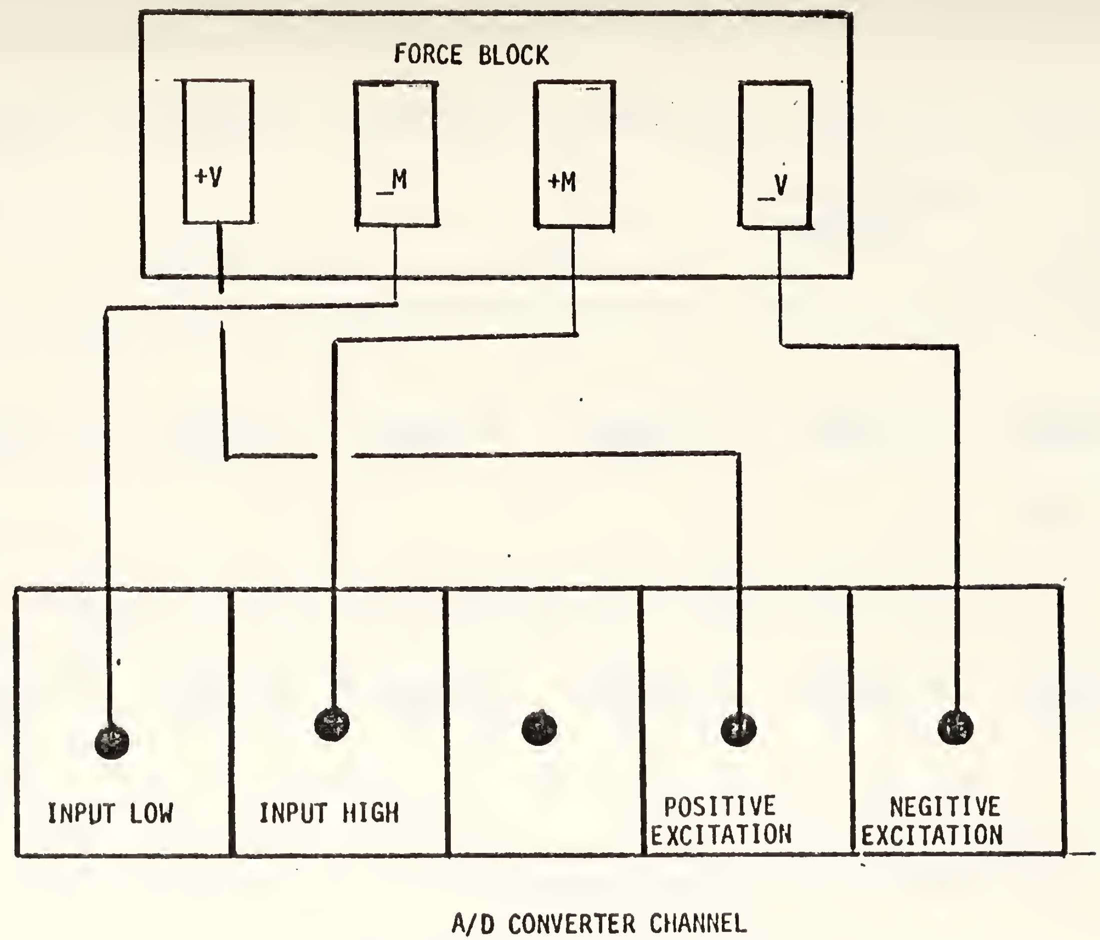


Figure 23. Force-Block-to-Channel Connection

CHANNEL 7	CHANNEL 8	CHANNEL 9	CHANNEL 16	CHANNEL 17	CHANNEL 18
G	H	I		EXCITATION VOLTAGE	
CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 13	CHANNEL 14	CHANNEL 15
D	E	F	O	P	M,N
CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 10	CHANNEL 11	CHANNEL 12
A	B	C	J	K	L

BUS CONNECTION TO A/D CONVERTER

Figure 24. Bus Connection-to-A/D Converter Connections

the force-block to A/D converter channel connection. Figure 24 depicts the current connection to the data acquisition/ control system bus from the sensors.

The data acquisition and analysis program is a fully automated system which integrates the use of the HP9826, HP3497A, and all sensor devices. The program can be divided into three sections:

1. <u>Data Acquisition</u> - Data is acquired from 15 different sensor devices. All system parameters are initialized and configuration types are inputted into the computer memory for future use. Ten readings are made on each sensor and a mean value for each is calculated and stored in memory.
2. <u>Data Conversion</u> - Input data conversion is completed by using calibration information obtained on each pressure transducer and force-block. The program takes the stored mean values from memory, and converts the input voltage to a pressure or force using the third order calibration polynomial for each sensor.
3. <u>Data Analysis</u> - This is the heart of the program in that all performance parameters are calculated and printed. It uses all of the above information to calculate mass flow rate of water, mass flow rate of air, total mass flow rate, thrust, mixture

ratio, exit velocity and all pressure information. The following equations are also used:

Exit Velocity = (Thrust/Total Mass Flow Rate)* g_c(ft/sec)

Mixture Ratio = $\dot{m}_{water}/\dot{m}_{air}$

Total Mass Flow Rate = $\dot{m}_{water} + \dot{m}_{air}$ $(\frac{lbm}{sec})$

Appendix L is the data acquisition program and sample output.

VI. EXPERIMENTAL RESULTS

Six test runs were made using the equipment described in the previous sections. It was found that the inlet pressure to the nozzle remained nearly constant for each setting. The testing was conducted by maintaining a constant air control valve setting and varying the mass flow rate of water. The regulator outlet pressure of the nitrogen bottle which controls the air valve was set at 30 psi and 15 psi. These settings correspond to nozzle inlet pressure of 35 ± 1.0 psi and 29 ± 1.0 psi respectively. For each nozzle inlet pressure, experimental data was obtained at varying mass ratios of water-to-air in the range of 2 to 13. These experiments were conducted with three discharge area ratios (A_{inlet}/A_{out}). Those ratios are: 3.586, 2.600, and 1.9259. The results of the six experimental tests are displayed in Tables II through VII.

Inlet air was limited to a maximum value of 40 psi. The 140PC pressure transducer's maximum output pressure is 40 psi, (see information on 140PC transducer Figure 21). The experimental system has the ability to reach higher pressures. The present configuration may be operated to 70 psig.

Table II. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN*********PRESSURE 29.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06050	0.01830	0.04220	2.30000	1998.00000	1950.39900	3.75000
0.10150	0.01840	0.08346	4.62000	1243.30000	1300.00000	3.92000
0.13650	0.01790	0.11860	6.64000	969.69990	1001.89900	4.11000
0.16630	0.01770	0.14860	8.39000	806.10000	830.60000	4.16000
0.19220	0.01770	0.17450	9.83000	710.69990	760.30000	4.24000
0.21490	0.01750	0.19730	11.26000	643.19990	695.50000	4.29000
0.23580	0.01750	0.21810	12.39000	602.50000	642.00000	4.41000
0.25550	0.01760	0.23790	13.51000	550.00000	620.89990	4.37000

Table III. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN*********PRESSURE 35.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06300	0.02080	0.04220	2.02000	2440.50000	2430.30000	4.77000
0.10410	0.02060	0.08346	4.05000	1536.10000	1611.50000	4.97000
0.13890	0.02030	0.11860	5.85000	1192.19900	1240.69900	5.14000
0.16840	0.01980	0.14860	7.50000	1007.30000	1031.30000	5.27000
0.19450	0.02000	0.17450	8.73000	880.83000	930.80000	5.32000
0.21720	0.01990	0.19730	9.93000	810.60000	860.75000	5.47000
0.23820	0.02000	0.21810	10.89000	735.69990	810.50000	5.44000
0.25750	0.01950	0.23790	12.18900	669.19990	715.30000	5.34000

Table IV. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.62500 SQ.IN*********PRESSURE 29.00000 PSI

MASS FLOW RATE TOTAL	AIR	WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06040	0.01820	0.04220	2.32000	1834.50000	1880.30000	3.44000
0.10150	0.01810	0.08346	4.61000	1158.00000	1201.19900	3.66000
0.13660	0.01800	0.11860	6.59000	937.80000	953.60000	3.98000
0.16650	0.01790	0.14860	8.32000	802.19990	803.10000	4.15000
0.19220	0.01770	0.17450	9.85000	688.60000	749.19990	4.21000
0.21510	0.01780	0.19730	11.10000	643.19990	702.10000	4.30000
0.23550	0.01740	0.21810	12.60000	589.89990	670.10000	4.32000

Table V. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.62500 SQ.IN*********PRESSURE 35.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.09370	0.02900	0.04220	2.02000	2165.89900	2210.30000	4.24000
0.13910	0.02050	0.11860	5.77000	1097.10000	1153.10000	4.74000
0.16900	0.02050	0.14860	7.27000	940.50000	998.39990	4.94000
0.19980	0.02030	0.17450	8.60000	832.89990	885.30000	5.04000
0.21760	0.02030	0.19730	9.72000	765.39990	801.60000	5.17000
0.23820	0.02010	0.21810	10.87000	720.50000	753.39990	5.32000
0.25770	0.01890	0.23790	12.03000	674.80000	700.30000	5.40000

Table VI. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.84375 SQ.IN*********PRESSURE 29.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06110	0.01890	0.04220	2.23000	1586.69900	1653.39900	3.01000
0.10210	0.01860	0.08346	4.48000	1069.10000	1101.60000	3.39000
0.13700	0.01840	0.11860	6.44000	850.39990	900.89990	3.61000
0.16680	0.01820	0.14860	8.19000	754.69990	791.10000	3.91000
0.19250	0.01800	0.17450	9.69000	655.60000	720.10000	3.92000
0.21560	0.01820	0.19730	10.84000	596.80000	675.30000	3.99000
0.23610	0.01800	0.21810	12.14000	576.10000	638.19990	4.22000
0.25560	0.01770	0.23790	13.46000	570.50000	610.50000	4.52000

Table VII. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.84375 SQ.IN*********PRESSURE 35.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06350	0.02130	0.04220	1.98000	1727.39900	1807.60000	3.40000
0.10440	0.02090	0.08346	3.99000	1081.50000	1102.30000	3.50000
0.13900	0.02040	0.11860	5.82000	891.12980	913.80000	3.85000
0.16890	0.02030	0.14860	7.31000	721.50000	810.39990	3.78000
0.19460	0.02010	0.17450	8.70000	691.89990	741.10000	4.18000
0.21690	0.01960	0.19730	10.10000	604.19990	675.19990	4.07000
0.23810	0.02000	0.21810	10.90000	583.50000	660.00000	4.35000
0.25780	0.01980	0.23790	12.00000	516.96990	654.39990	4.42000

VII. DISCUSSION

The results of this investigation are in two parts; the experimental test results and the computer outputs based on initial conditions similar to those of the experiments.

The key variables are: the nozzle overall area ratio A_R, liquid/air mass flow ratio, nozzle exit velocity, nozzle supply pressure, nozzle thrust, and the nozzle axial pressure profiles. Figures 25 through 34 present the exit velocity vs. mass ratio results for the experiment and computer output. Figure 29-34 illustrates the comparison of the experimental results and the corresponding computer output. Figure 35 illustrates the variation of nozzle thrust with mass ratio for different area ratios and inlet pressures. Figures 36 and 37 present the axial pressure profiles.

In all cases the exit plane velocity decreases as the liquid/air mass ratio is increased. In the low mass ratio range (i.e., less than ≈ 5) the velocity decrease is very pronounced. Past a mass ratio value of ≈ 10 the velocity of the mixture becomes relatively insensitive to the mixture ratio. This is as would be expected. For the same inlet conditions there is a fixed amount of energy available for conversion to its kinetic form. In the nozzle process the energy is conserved and thus an increasing mass ratio is

manifested in a decreasing exit plane velocity. In all cases the agreement between the experimental tests and the analytic predictions are with in $\simeq$ 10%.

There also was apparent and a consistent trend with respect to the nozzle area ratio and the exit velocity. As the nozzle exit area was increased the exit velocity of the mixture decreased. The effect seems to be more pronounced at the lower mass ratios. This trend was confirmed by observations of the actual flow field in the nozzle. If the exit area was increased significantly (beyond the max area used in those tests) there was evident an abrupt and severe separation within the diverging portion of the nozzle passage. This was accompanied by a drastic decrease in exit velocity as evidenced by the output from the thrust target. It appears that the diverging portion of the nozzle, at a certain point, starts to behave as a subsonic diffuser and hence experiences an adverse pressure gradient. This reasoning is in part confirmed by the pressure profiles identified in Figures 36 and 37.

The relationship between measured thrust and mass ratio (Figure 35) indicates a slightly increasing trend. This may be explained by considering the following. Each set of data points (at constant inlet air pressure and constant nozzle exit area) is developed by varying the mass ratio. This, in turn, is achieved by increasing the liquid rate by increasing the liquid supply pressure. The net result is an

increase in the liquid inlet velocity or an increase in the inlet energy level. Thus a particular data set is not truly at a constant inlet energy level but is increasing.

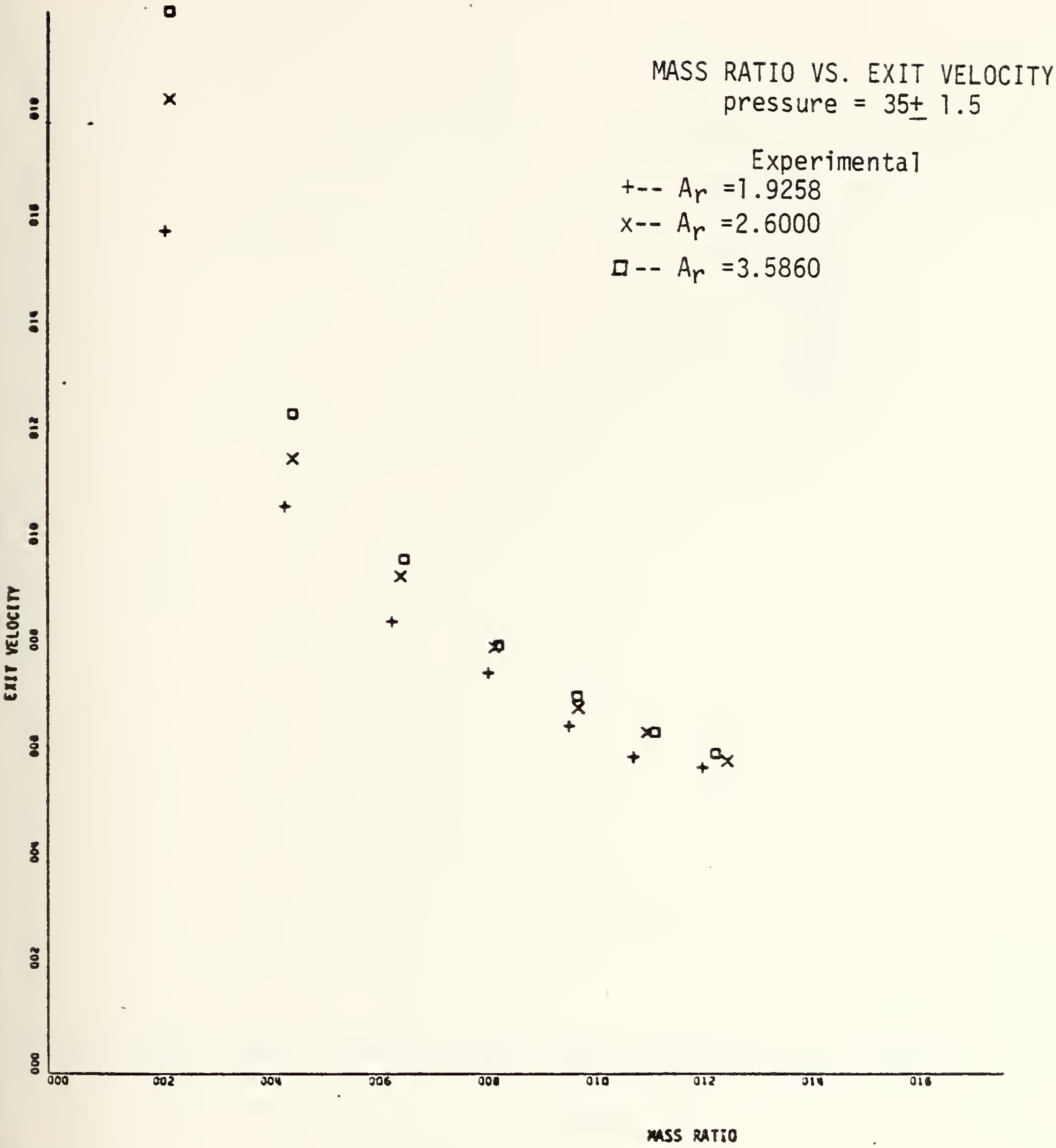
Perhaps the major discrepancy between the experimental test results and the computer analytic model is evidenced in the axial pressure profiles of Figures 36 and 37. It is clearly evident that at a certain point the nozzle passage reverts from a nozzle to a diffuser. This transition point occurs slightly downstream of the throat and the pressure starts to increase.

Unfortunately the computer analytic model requires a pressure profile as an input. Furthermore the pressure profile must be continuously decreasing. Thus the profile as obtained from the experiment are not directly useable. The situation is examined with the aid of Figure 38. Curve A is a typical axial pressure distribution as obtained from the experiment. Curve B is a pressure distribution used by Elliott in the application of his computer program. Pressure profiles C and D were arbitrarily defined and the exit plane velocity for each was calculated. Velocity variation in the range of 1% is evident. It appears that the final exit velocity is relatively insensitive to the actual pressure profile in the nozzle.

In light of the preceeding difficulty of matching the experimental pressure profile to the computer model and the

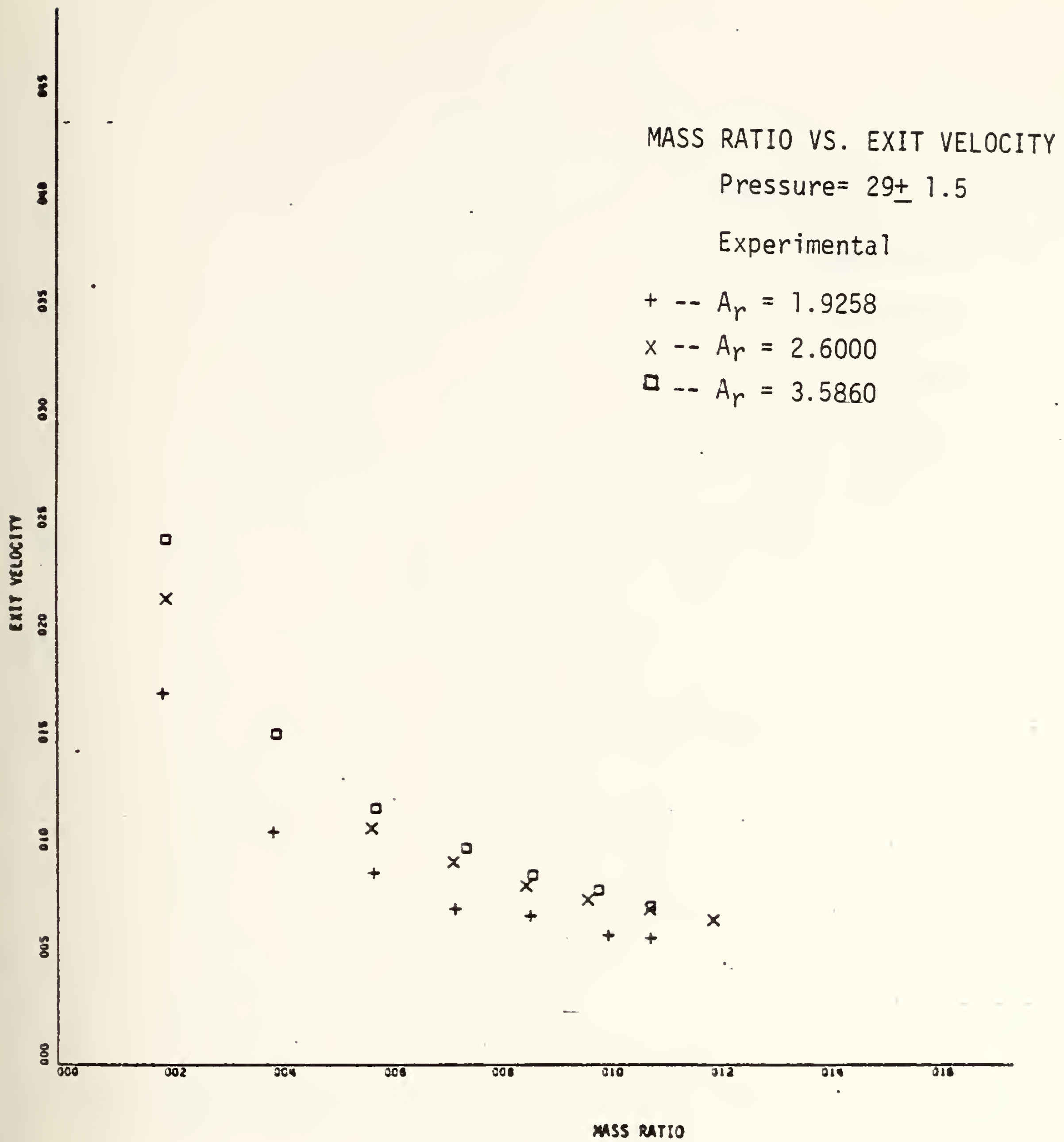
apparent flexibility of the type of pressure profile it was decided to employ a form of profile D of Figure 38. Thus instead of using the actual experimental pressure data as an input in the computer model, a profile resembling curve D was developed for each inlet pressure case.

It is apparent that within certain rather wide limits the Elliott computer model yields results that correspond within 10% to results obtained from the experiment. The general trends have been confirmed and their behavior has revealed nothing unexpected. The conclusion of Elliott [Ref. 1] has been largely substantiated. "It is very difficult to design a bad or a good dual-phase nozzle."



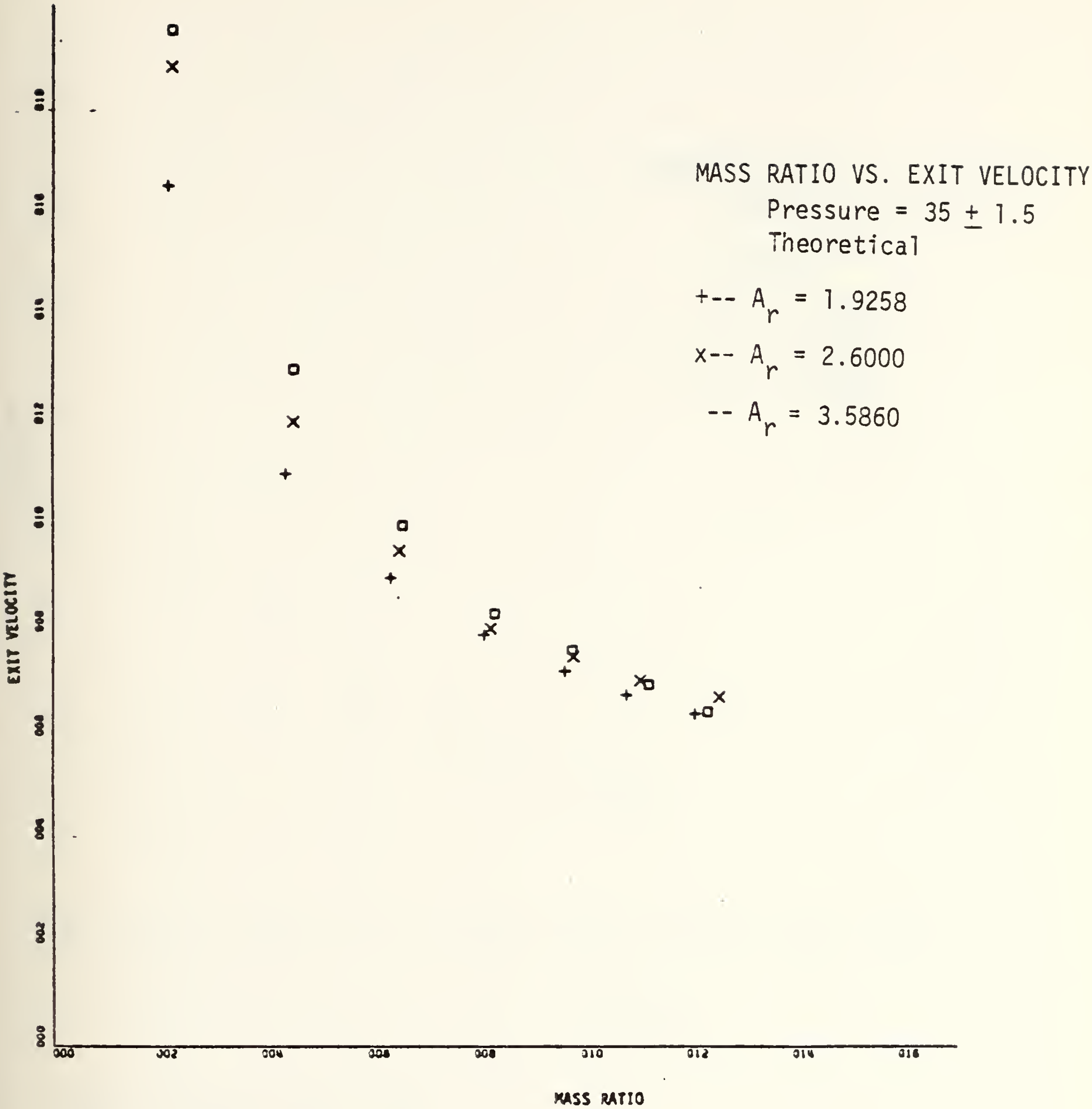
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 25. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Experimental



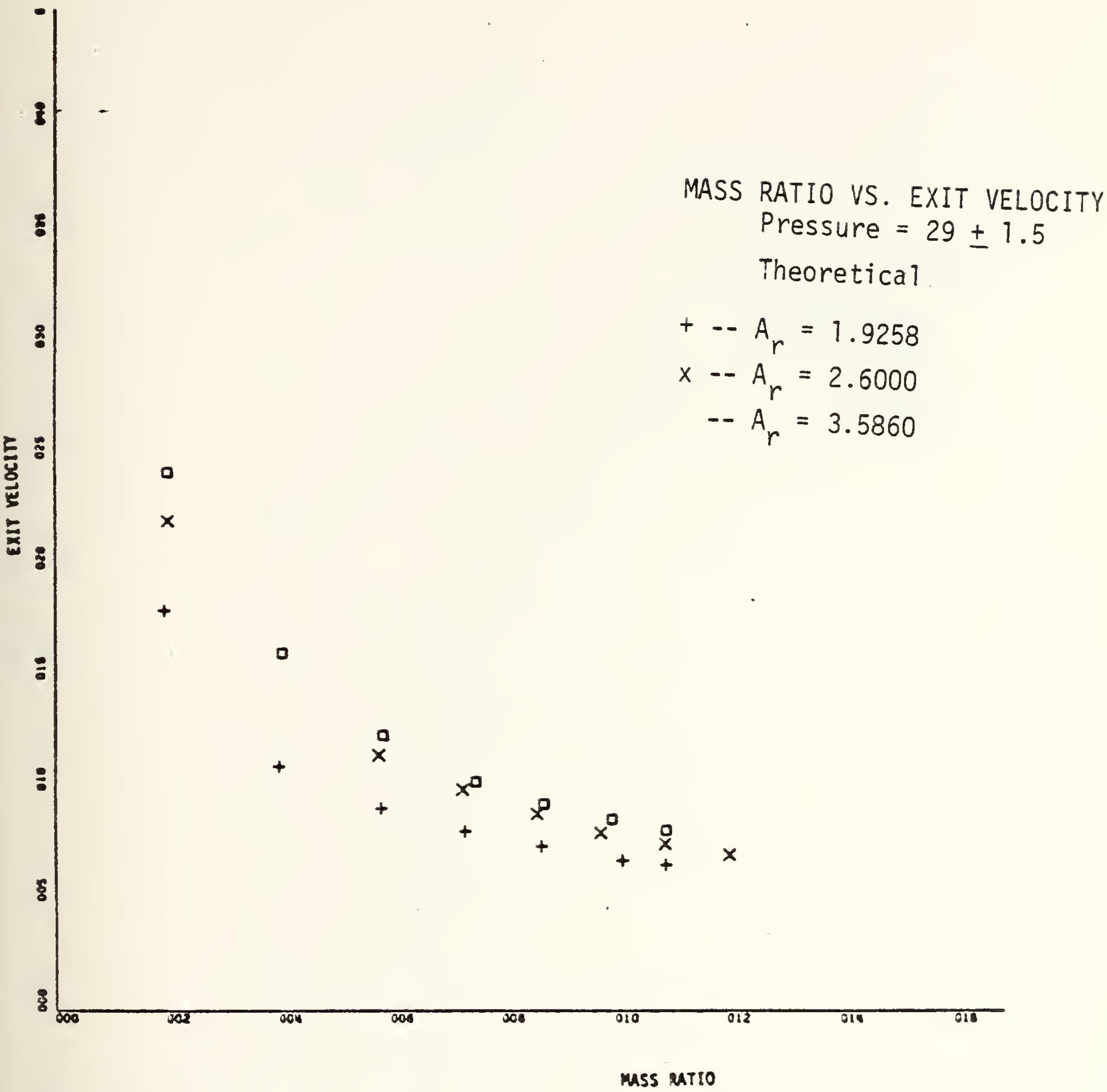
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 26. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Experimental



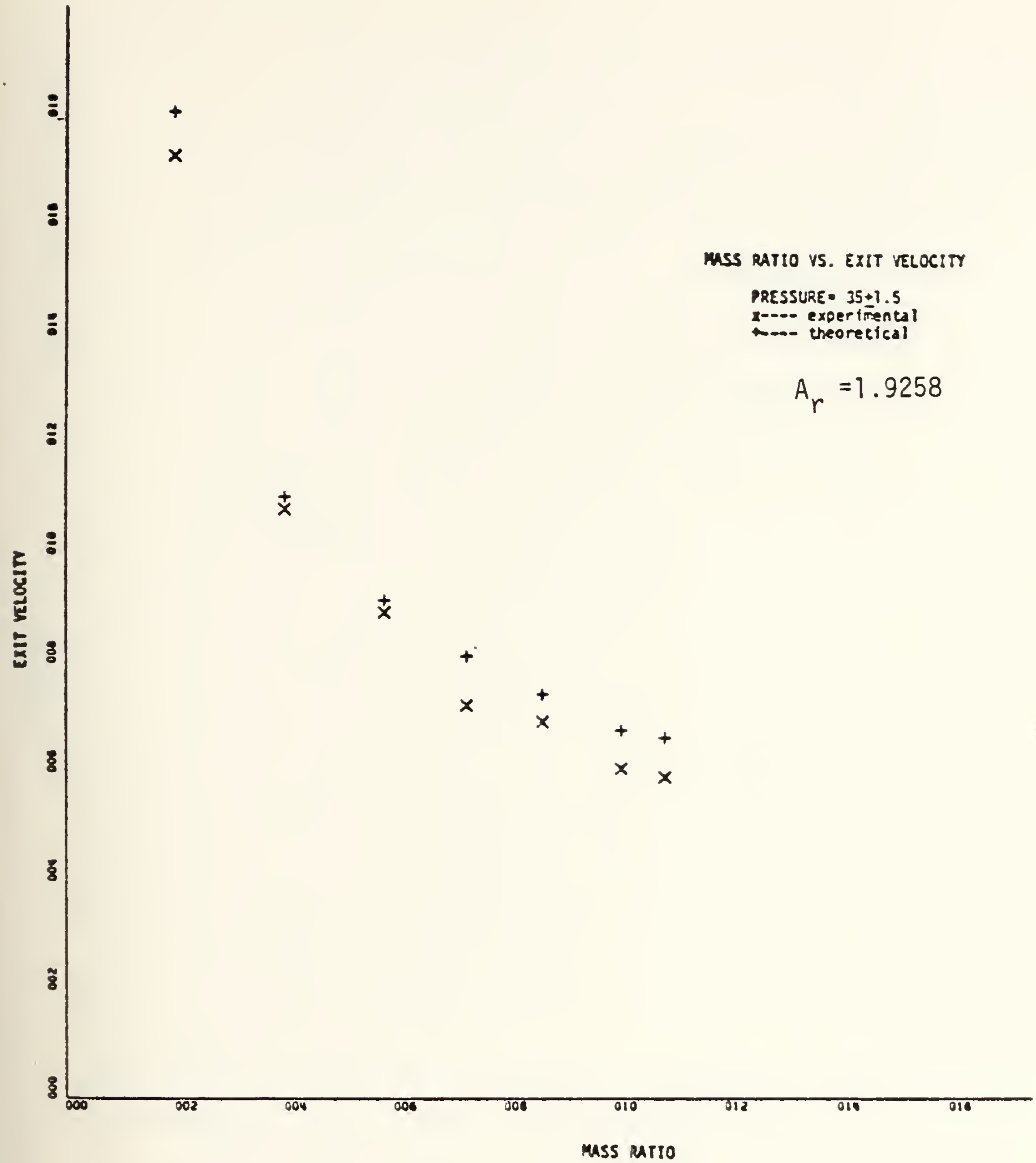
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 27. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Theoretical



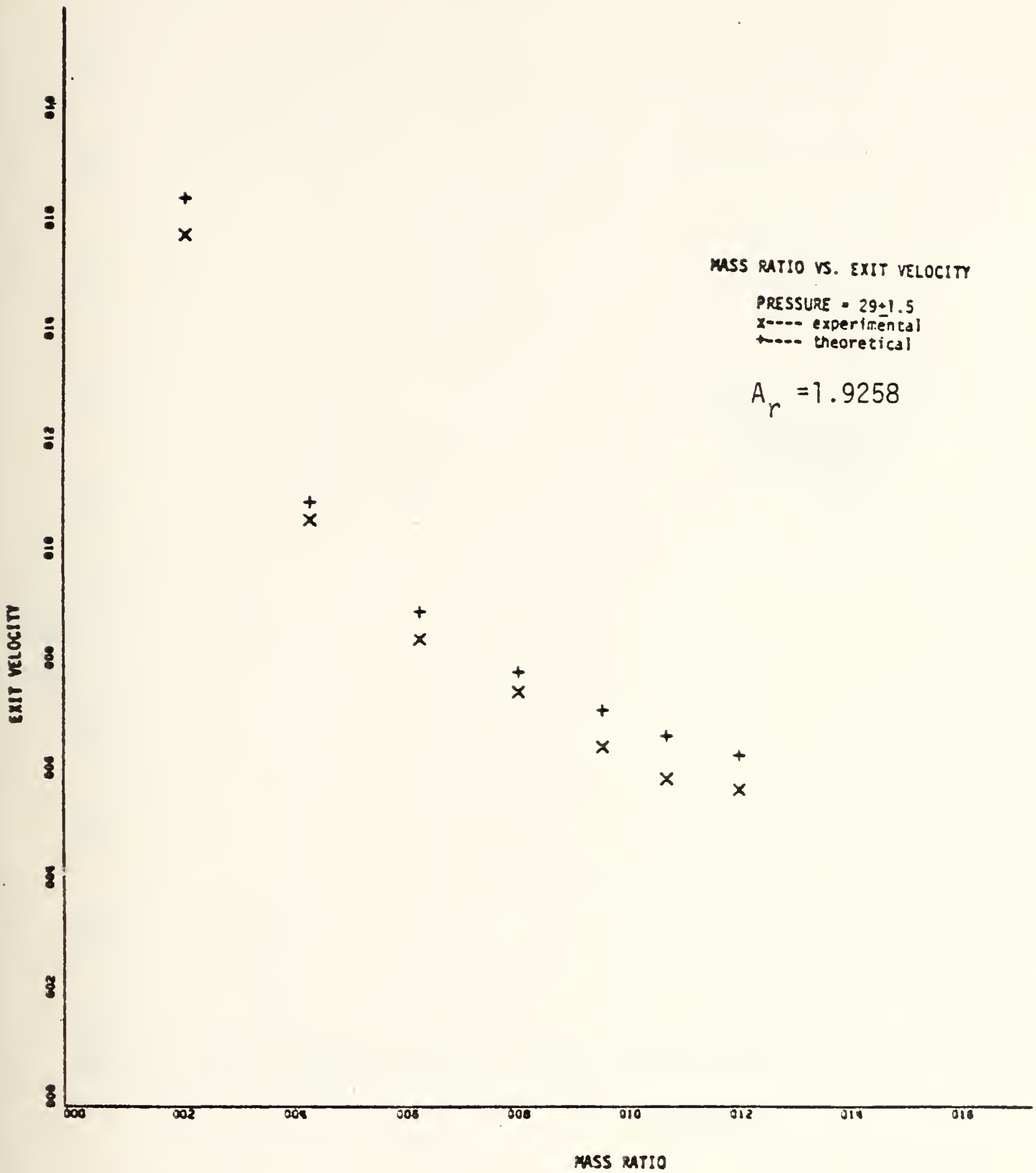
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 28. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Theoretical



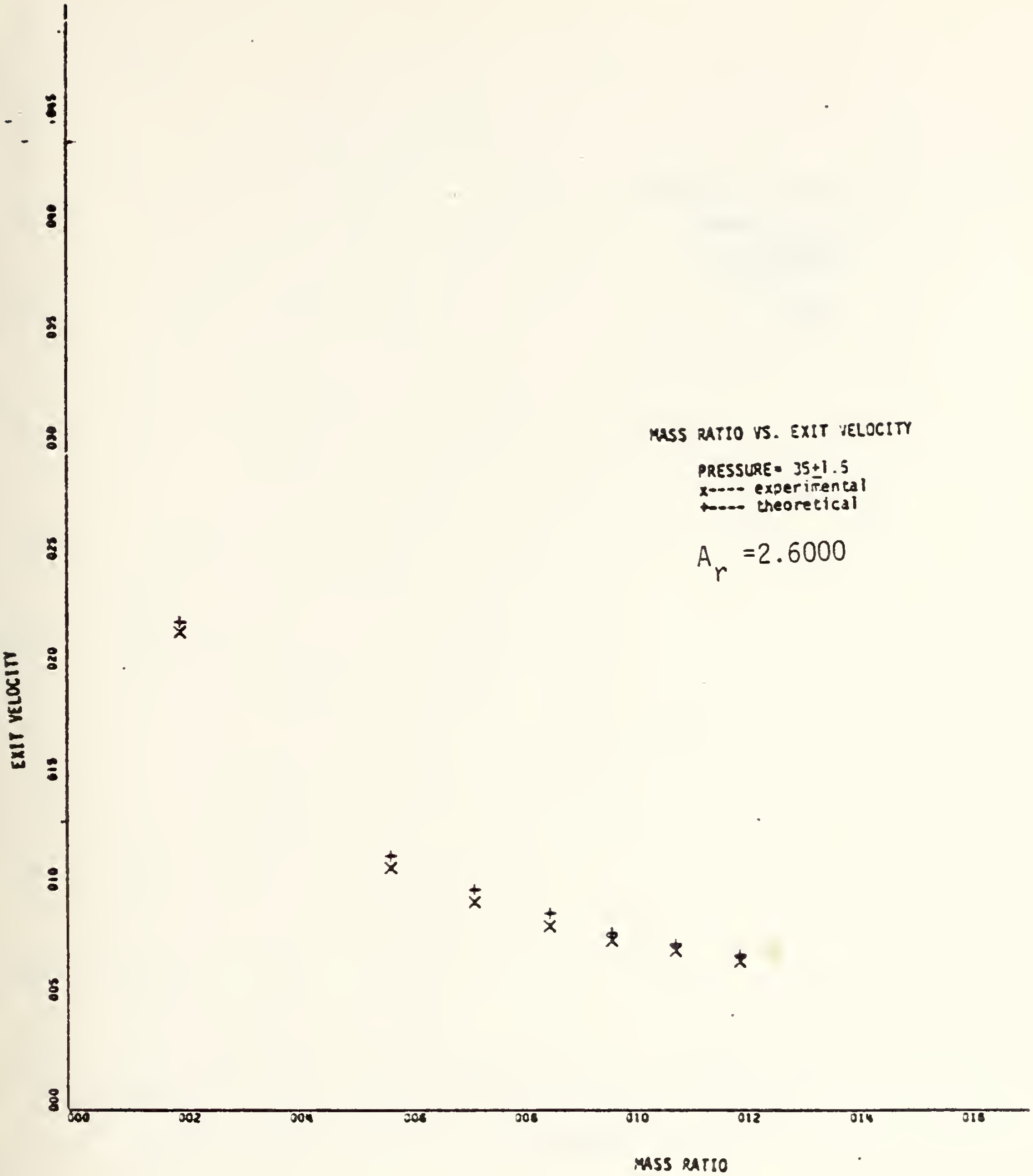
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 29. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .84375



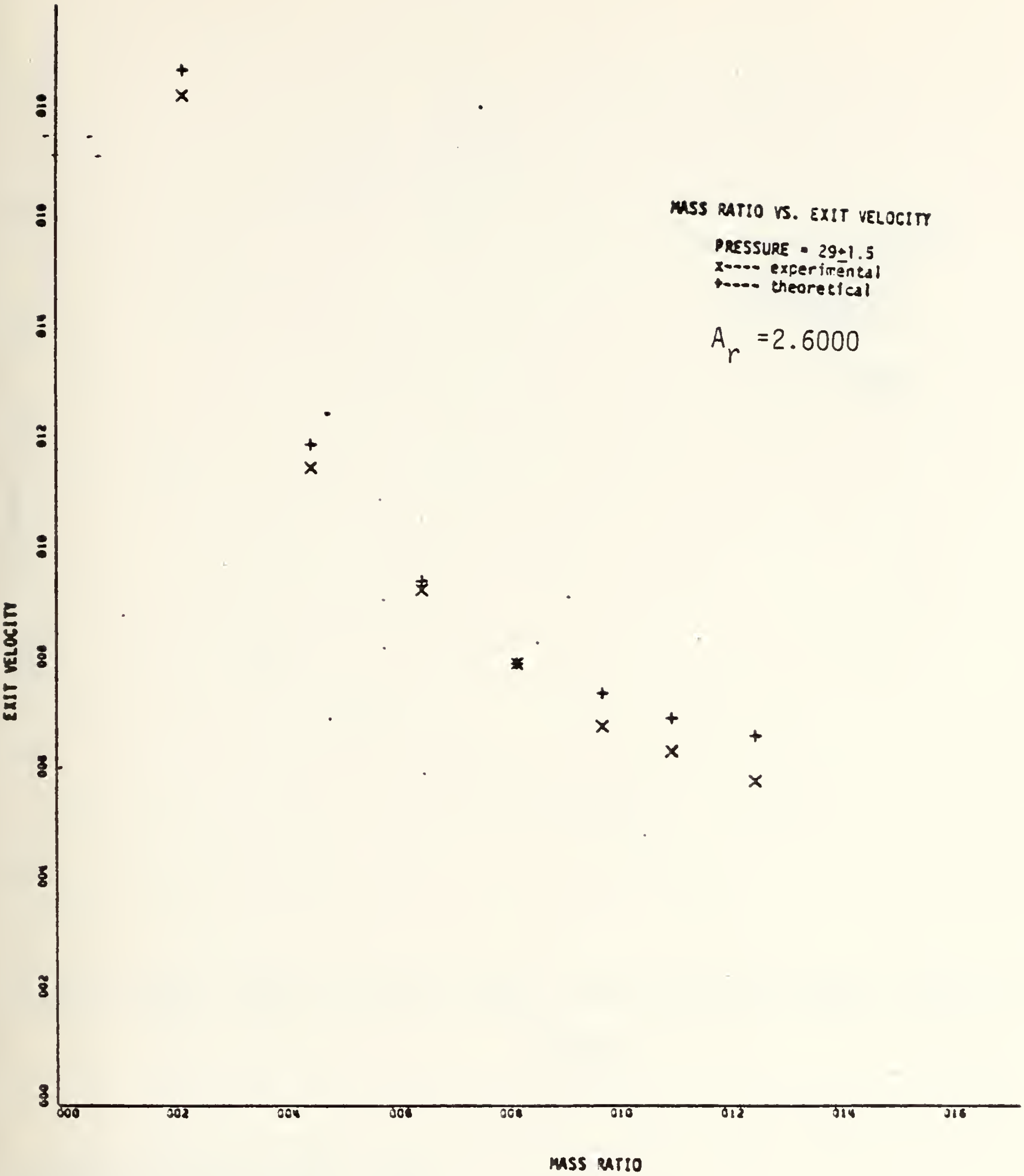
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 30. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .84375



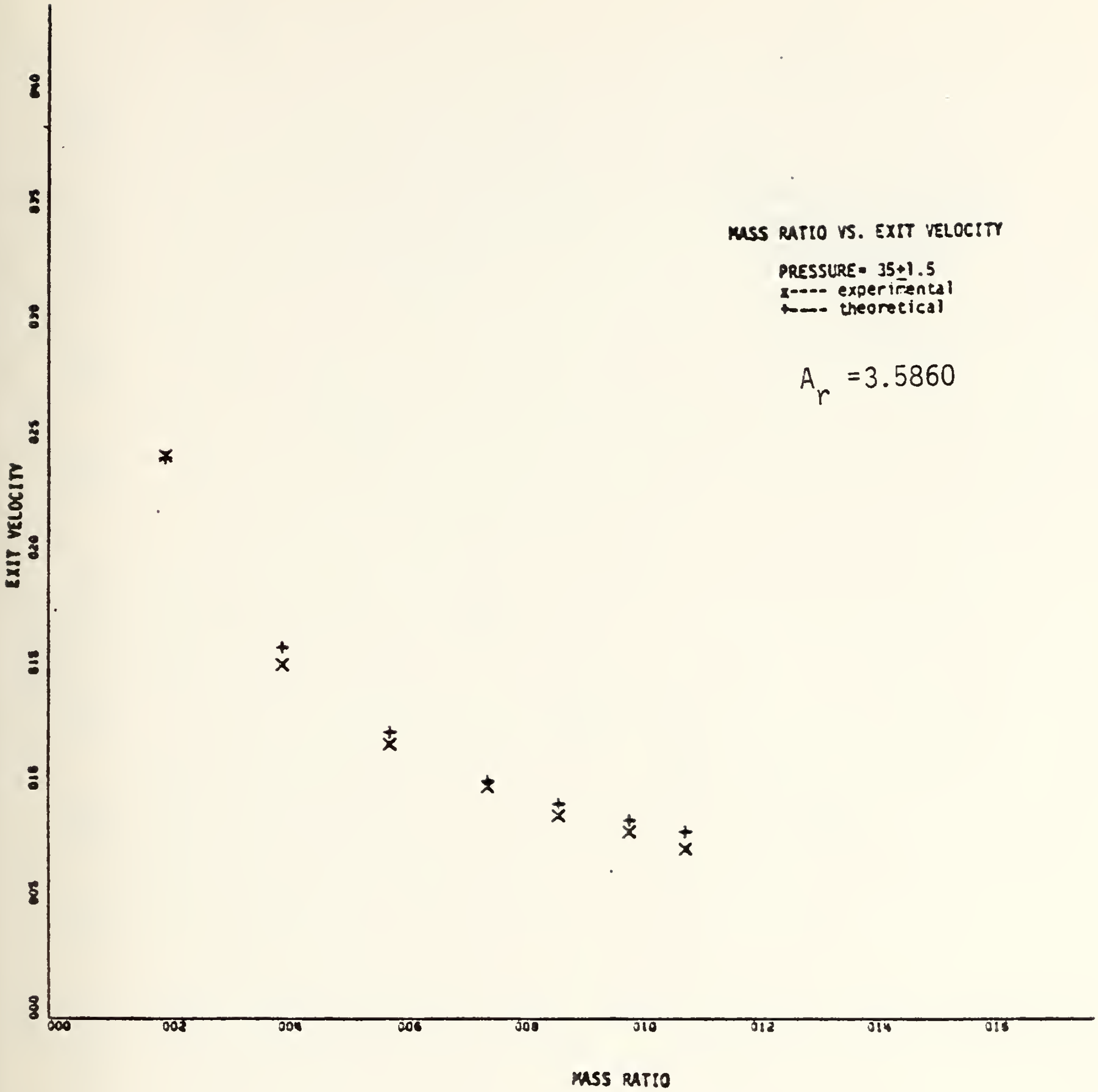
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 31. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .62500



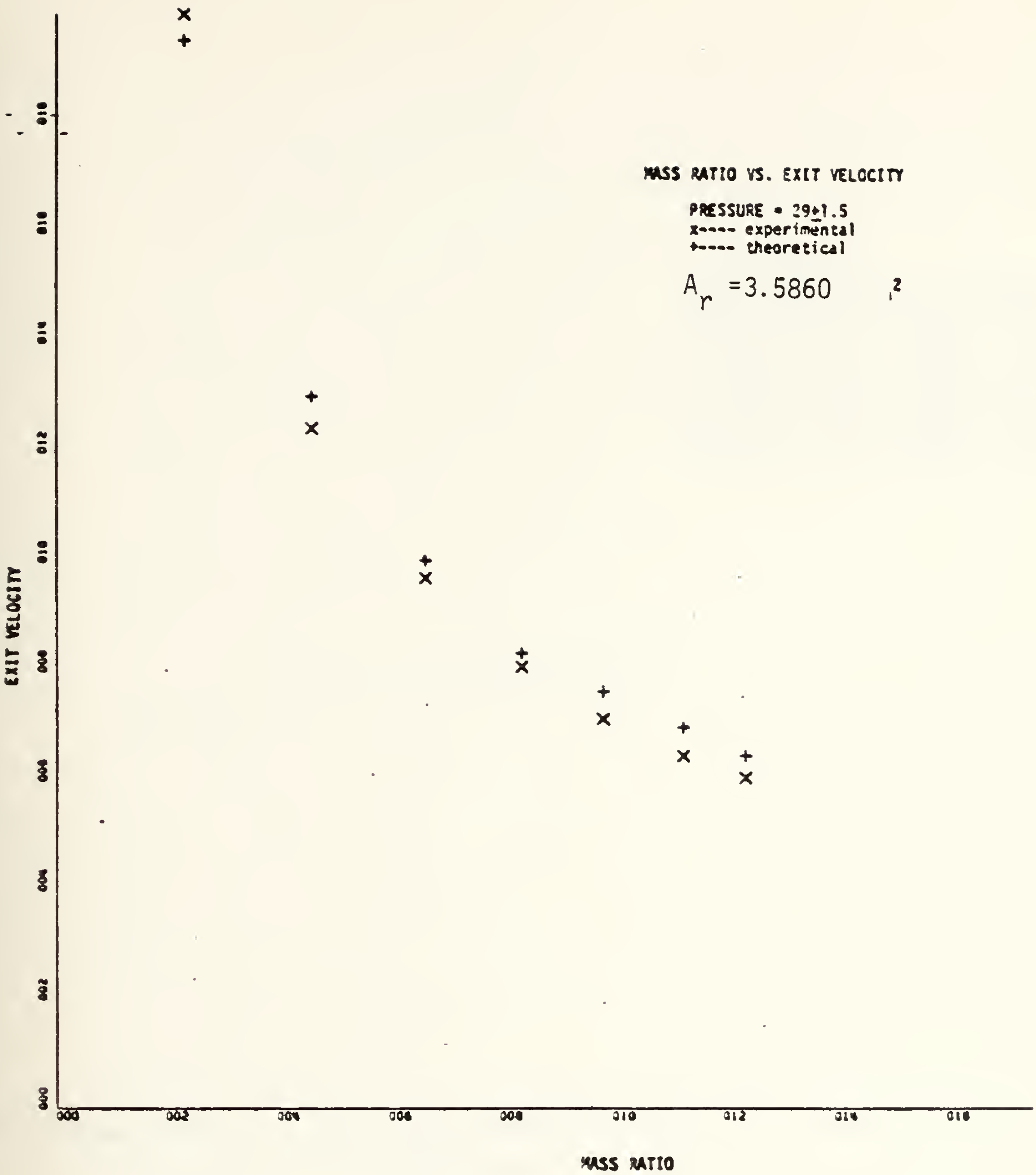
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 32. Mass Ratio vs. Exit Velocity at
Pressure = 29±1.5psi Area = .62500



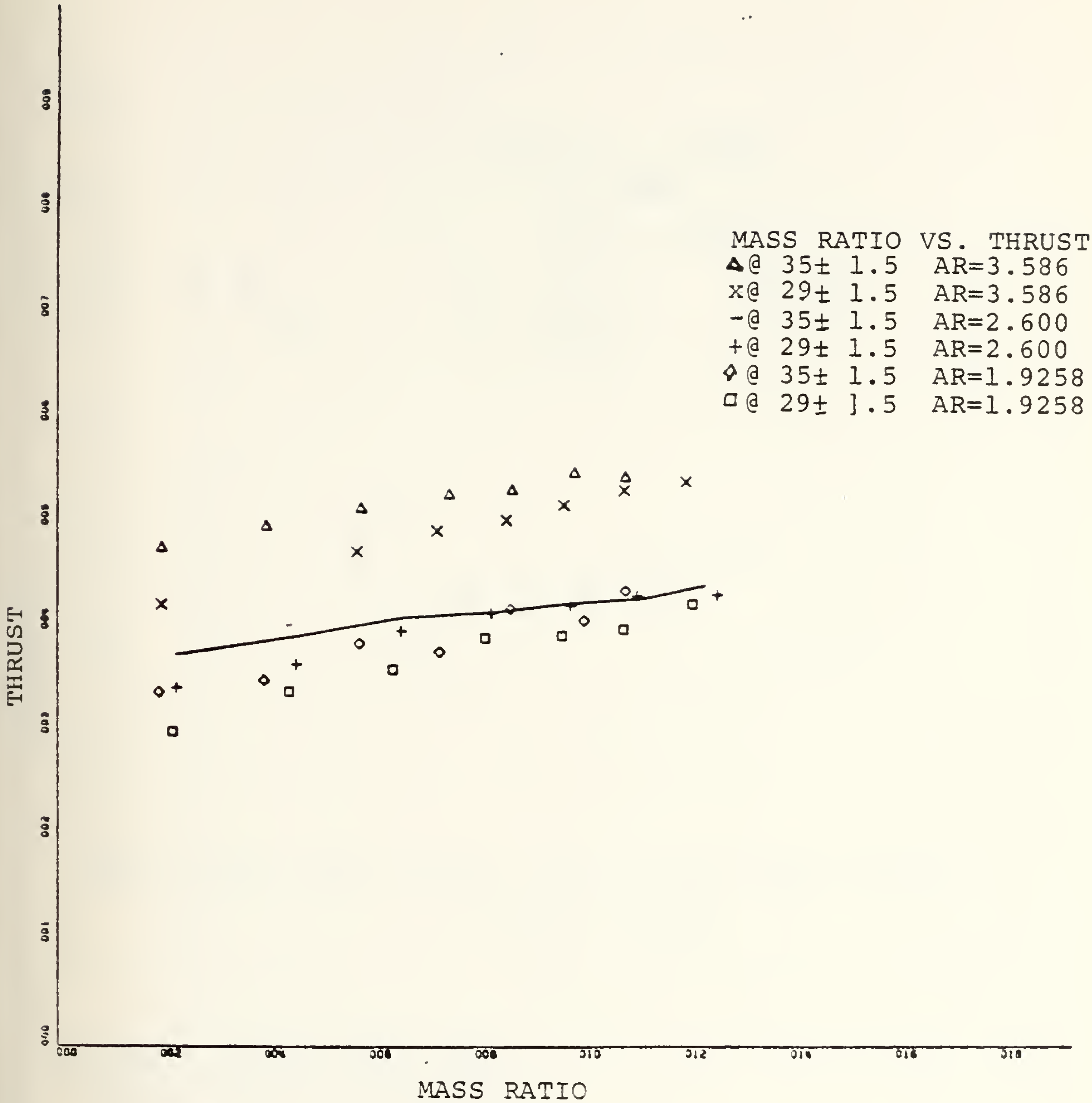
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 33. Mass Ratio vs. Exit Velocity at
Pressure = 35±1.5psi Area = .45313



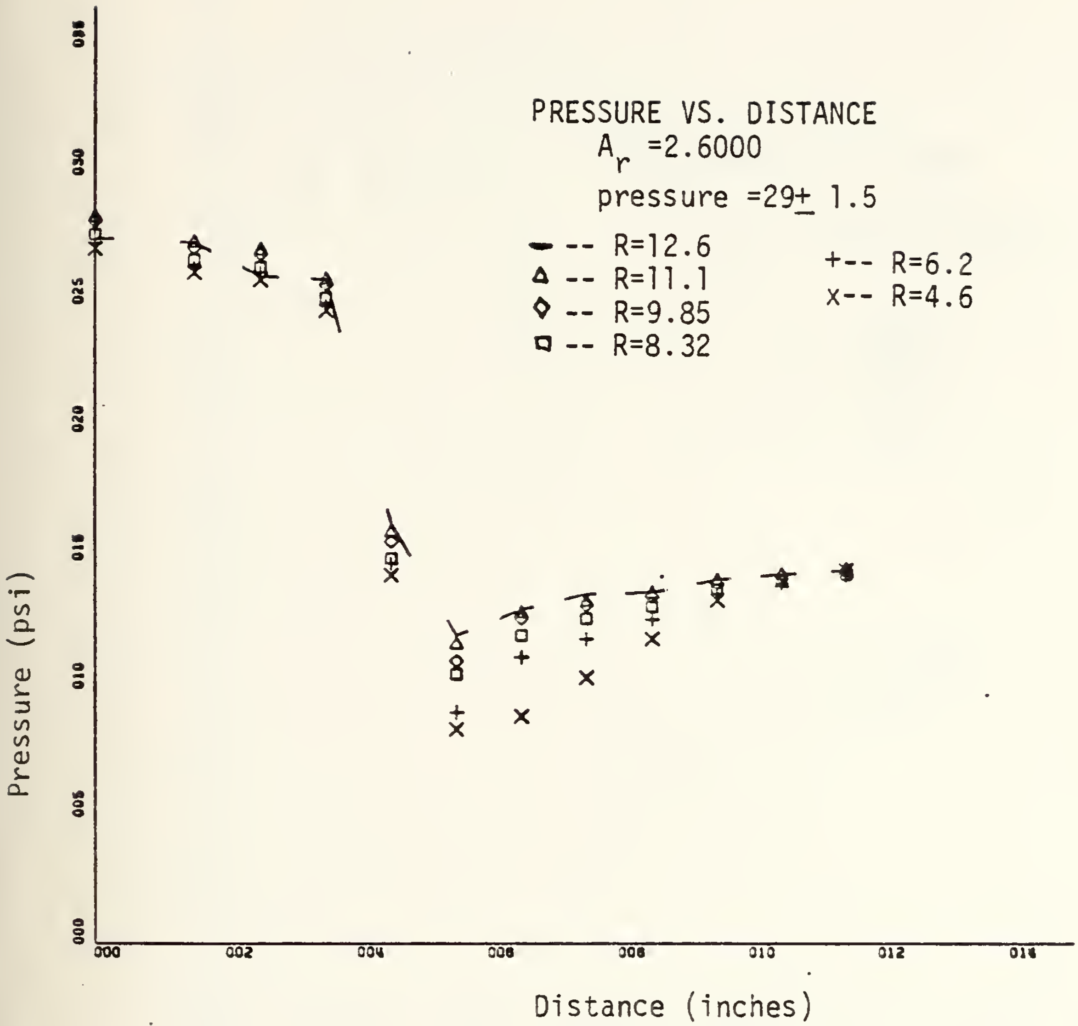
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 34. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .45313



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=1.00E+00 UNITS INCH.

Figure 35. Mass Ratio vs. Thrust Curve



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+00 UNITS INCH.

Figure 36. Pressure vs. Distance at Pressure = 29±1.5 Exit Area = .625 sq. in.

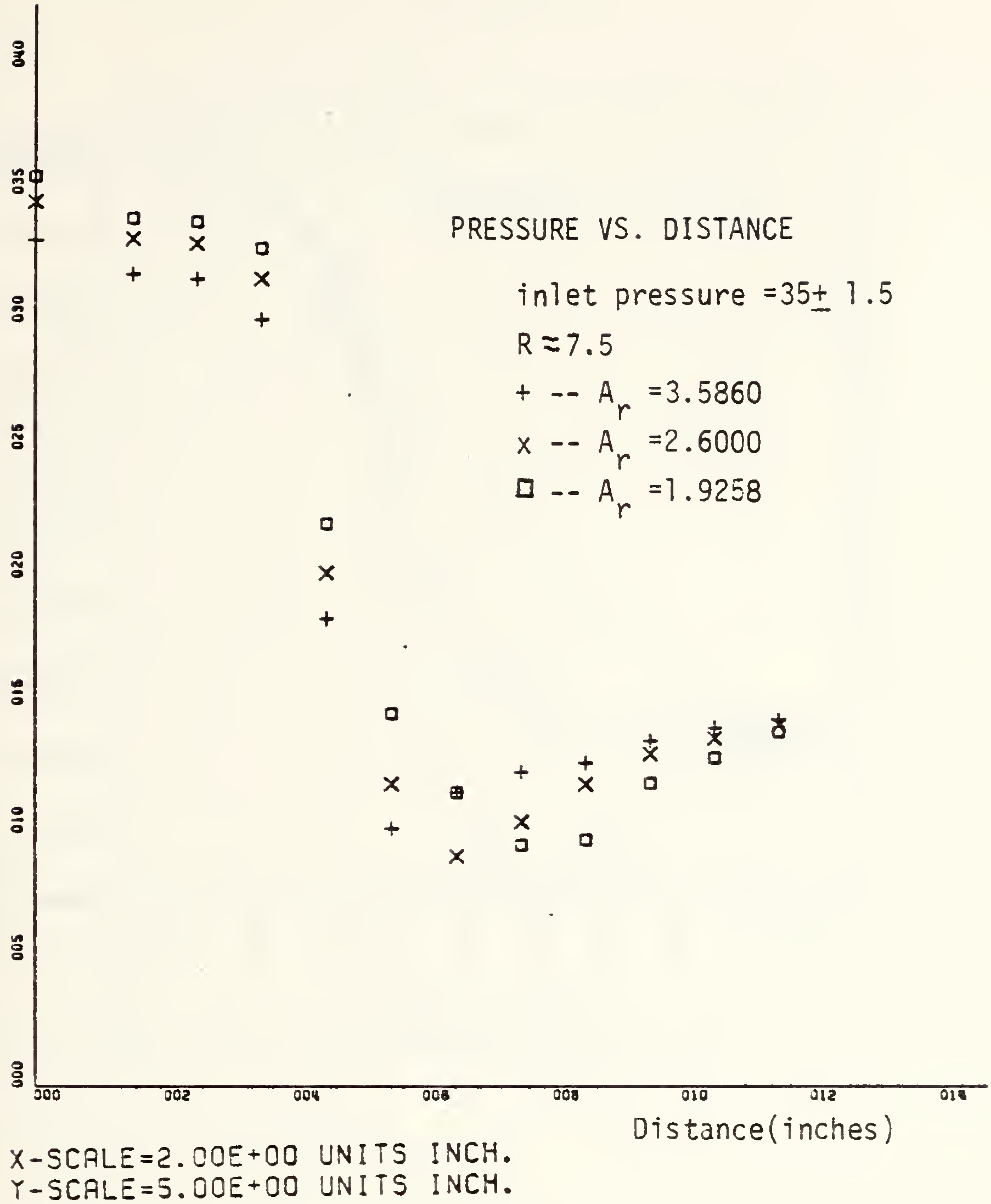


Figure 37. Pressure vs. Distance at
R ≃ 7.5 P = 35psi±1.5

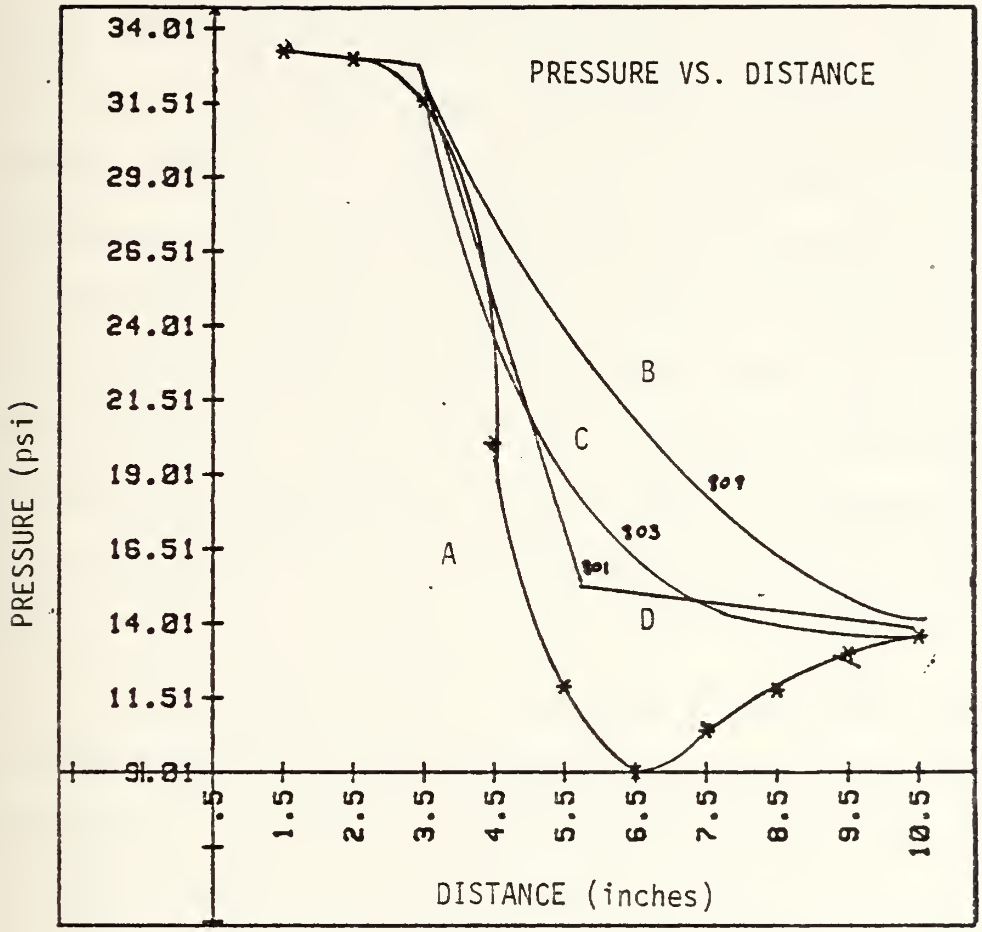


Figure 38. Various Pressure Profiles & Corresponding Exit Velocities

VIII. CONCLUSION

A set of experiments were conducted with an air-water mixture flowing at a mass ratio from 2 to 13. The experiments correlated well with a dual-phase two-component computer program. It appears that the program will permit prediction of the exit velocities to an accuracy of 10% for two-phase nozzles. At small nozzle area ratios, accuracies between theoretical and experimental are better; approximately 5%. All predicted velocities are higher than measured experimental values due to estimation of the drop size and the initial kinetic energy of the liquid at injection point.

It would be desirable to develop a drop size subroutine to better estimate varying drop size. The experimental system can be improved by velocity measurement devices at the inlet. Input of the gas and liquid velocities are necessary in the dual-phase two-component program and thus these measurement devices are vital for better accuracy.

Due to the insensitivity of the pressure distribution, it appears that any reasonable approximation to the pressure profile can be employed in the two-phase two-component flow program. For a given nozzle exit area and inlet pressure, a pressure distribution curve can be obtained through the experimental system. This distribution can therefore be used to obtain good results.

APPENDIX A: SAMPLE P(X) PROGRAM

```
$JOB
         REAL P(75),X(75),PX,FX
         INTEGER N,K,NP1,NX
         A=35.3654923
         B=5.6858777
         C=14.39
         D=0.04731
         E=.444802
         NX=75
         P1=35.0
         P2=8.0
         PREF=8.0
         XREF=10.0
         N=74
         NP1=N+1
         PX=(P1-P2)/380
         DO 10 K=1,N
            X(K)=7.7*(K-1)/(N-1)
            DX=7.7-X(K)
            IF (X(K).LE.0.7)P(K)=P2+PX*E*(855-A*(X(K)+.5)**B)
            IF (X(K).GT.0.7) P(K)=P2+PX*E*(C*DX+D*DX**4.9)
            IF(K .EQ.1)GO TO 10
            FRAC=(P(K-1)-PREF)/(P(K-1)-P(K))
            IF (FRAC.GE.0 .AND.FRAC.LE.1)XXREF=X(K-1)+FRAC*(X(K)-X(K-1))
    10   CONTINUE
         FX=XREF/XXREF
         DO 15 K=1,N
    15      X(K)=FX*X(K)
         X(NP1)=1E5
         P(NP1)=1E5
         DO 20 K=1,75,3
    20     WRITE(6,100)P(K),X(K),P(K+1),X(K+1),P(K+2),X(K+2)
         STOP
   100   FORMAT(6E12.6)
         END
```

APPENDIX B: SAMPLE HEAT CAPACITY PROGRAM

```
$JOB
      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
     1   D6,D7,D8,D9,M,W
      INTEGER N,J,I,O,K,X
      DATA PRESS/.01,.4,.7,1.0,4.0,7.0,10.0,40.0,70.0/
      READ (5,100)((TABLE(J,I),I=1,10),J=1,16)
      DO 10 N=1,9
        PRESS(N)=PRESS(N)*14.696
10    CONTINUE
      DO 20 J=1,16
        DO 30 I=2,10
          TABLE(J,I)=TABLE(J,I)*.0685590
30      CONTINUE
20    CONTINUE
      M=0.0
      DO 91 J=1,16
        TEMP(J) =400.0 +M
        M=M+10.0
        W=0.0
        DO 90 I=1,11
          P(I)=W
          N=1
          Q=N+1
          W=100.0+W
15        IF (ABS(TEMP(J)- TABLE(N,1)).GT .001) GO TO 25
            Q=0
            GO TO 50
25        CONTINUE
          IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
     1      GO TO 50
            N=1+N
            Q=N+1
            GO TO 15
50        CONTINUE
          K=2
          X=K+1
          IF(P(I).GT. .0001)GO TO 49
            X=0
            GO TO 60
```

```
45      IF(ABS(P(I) -PRESS(K)).GT..001) GO TO 55
          X=0
          GO TO 60
55      CONTINUE
        IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GO TO 60
          K=1+K
          X=K+1
          GO TO 55
60      CONTINUE
        IF((C.NE. 0) .OR. (X .NE. 0))GO TO 61
          ANS(I)=TABLE (N,K)
          GO TO 90
        CONTINUE
61      IF(C .NE. 0)  GO TO 63
          D1 = TABLE(N,K)-TABLE(N,X)
          D7 = PRESS(K-1) -PRESS(X-1)
          D8 =PRESS(K-1)-P(I)
          D9 =(D8/D7)*D1
          ANS(I)=D9+TABLE(N,K)
          GO TO 90
63      CONTINUE
        IF (X.NE. 0) GO TO 70
          D1 = (TABLE(N,K)-TABLE(Q,K))
          D3 = TABLE(N,1)-TABLE(Q,1)
          D4 =TABLE(N,1) -TEMP(J)
          D9 =(D4/D3)*D1
          ANS(I) =D9+(TABLE(N,K))
          GO TO 90
70      CONTINUE
        D1 =TABLE(N,K)-TABLE(Q,K)
        D2=TABLE(N,X)-TABLE(Q,X)
        D3=TABLE(N,1)-TABLE(Q,1)
        D4=TABLE(N,1)-TEMP(J)
```

```
      C5=(C4/D3)*D1
      C6=(C4/D3)*D2
      D10=C5+TABLE(N,K)
      D11=C6+TABLE(N,K)
      D7=(PRESS(K-1)-PRESS(X))
      D8=PRESS(K-1)-P(I)
      D9=(D8/D7)*(D10-D11)
      ANS(I)=D9+D10
90    CONTINUE
      WRITE(6,150) TEMP(J)
      WRITE(6,200)P(1),ANS(1),P(2),ANS(2),P(3),ANS(3)
      WRITE(6,200)P(4),ANS(4),P(5),ANS(5),P(6),ANS(6)
      WRITE(6,200)P(7),ANS(7),P(8),ANS(8),P(9),ANS(9)
      WRITE(6,250)P(10),ANS(10),P(11),ANS(11)
91    CONTINUE
      STOP
100   FORMAT(10F7.4)
150   FORMAT(F12.6)
200   FORMAT (6F12.6)
250   FORMAT (4F12.6)
      END
$ENTRY
360.0   3.4923  3.4935  3.5020  3.5062  3.5495  3.5950  3.6427  4.256   5.132
396.0   3.4928  3.4971  3.5005  3.5038  3.5379  3.5731  3.6095  4.036   4.559
414.0   3.4933  3.4972  3.5002  3.5032  3.5337  3.5651  3.5972  3.963   4.392
432.0   3.4938  3.4973  3.5000  3.5028  3.5302  3.5584  3.5871  3.906   4.265
450.0   3.4946  3.4978  3.5003  3.5027  3.5277  3.5531  3.5789  3.860   4.166
468.0   3.4954  3.4983  3.5005  3.5028  3.5255  3.5485  3.5719  3.822   4.090
486.0   3.4964  3.4990  3.5011  3.5031  3.5240  3.5450  3.5663  3.790   4.025
504.0   3.4976  3.5000  3.5019  3.5039  3.5228  3.5420  3.5614  3.763   3.970
522.0   3.4990  3.5012  3.5030  3.5047  3.5222  3.5398  3.5576  3.741   3.926
540.0   3.5006  3.5026  3.5043  3.5059  3.5220  3.5383  3.5546  3.722   3.889
558.0   3.5025  3.5044  3.5059  3.5074  3.5223  3.5374  3.5525  3.706   3.857
576.0   3.5045  3.5063  3.5076  3.5091  3.5229  3.5369  3.5508  3.692   3.831
594.0   3.5069  3.5085  3.5098  3.5112  3.5240  3.5371  3.5500  3.680   3.808
612.0   3.5094  3.5109  3.5121  3.5134  3.5254  3.5375  3.5497  3.671   3.788
630.0   3.5122  3.5137  3.5148  3.5160  3.5273  3.5386  3.5460  3.662   3.771
720.0   3.5305  3.5316  3.5325  3.5333  3.5416  3.5500  3.5583  3.641   3.717
```

```
$JOB
      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
     1   D6,D7,D8,D9,M,W,MWS(20)
      INTEGER N,J,I,Q,K,X
      DATA PRESS/.01,.4,.7,1.0,4.0,7.0,10.0,40.0,70.0/
      READ (5,100)((TABLE(J,I),I=1,10),J=1,16)
      DO 10 N=1,9
        PRESS(N)=PRESS(N)*14.696
 10   CONTINUE
      DO 20 J=1,16
        DO 30 I=2,10
          TABLE(J,I)=TABLE(J,I)*.0807223
 30     CONTINUE
 20   CONTINUE
      M=0.0
      DO 92 J=1,16
        TEMP(J) =400.0 +M
        M=M+10.0
        W=0.0
        DO 91 I=1,11
          P(I)=W
          N=1
          Q=N+1
          W=100.0+W
 15       IF (ABS(TEMP(J)- TABLE(N,1)).GT .001) GO TO 25
            Q=0
            GO TO 50
 25       CONTINUE
          IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
     1      GO TO 50
            N=1+N
            Q=N+1
            GO TO 15
 50       CONTINUE
          K=2
          X=K+1
          IF(P(I).GT. .0001)GO TO 49
            X=0
            GO TO 60
 49       IF(ABS(P(I) -PRESS(K)).GT..001) GO TO 55
            X=0
            GO TO 60
```

```
55        CONTINUE
          IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GO TO 60
            K=1+K
            X=K+1
            GO TO 55
60        CONTINUE
          IF((C.NE. 0) .OR. (X .NE. 0))GO TO 61
            ANS(I)=TABLE (N,K)
            GO TO 90
          CONTINUE
61        IF(C .NE. 0)  GO TO 63
            D1 = (TABLE(N,K)-TABLE(N,X))
            D7 = (PRESS(K-1) -PRESS(X-1))
            D8 =PRESS(K-1)-P(I)
            D9 =ABS((D8/D7)*D1)
            ANS(I)=D9+TABLE(N,K)
            GO TO 90
63        CONTINUE
          IF  ().NE. C) GO TO 70
            D1 = (TABLE(N,K)-TABLE(Q,K))
            D3 = TABLE(N,1)-TABLE(Q,1)
            D4 =TABLE(N,1) -TEMP(J)
            D9 =ABS((D4/D3)*D1)
            ANS(I) =(TABLE(N,K))-D9
            GO TO 90
70        CONTINUE
          D1 =TABLE(N,K)-TABLE(Q,K)
          D2=TABLE(N,X)-TABLE(Q,X)
          D3=TABLE(N,1)-TABLE(Q,1)
          D4=TABLE(N,1)-TEMP(J)
```

```
      D5=ABS((D4/D3)*D1)
      D6=ABS((D4/D3)*D2)
      D10=TABLE(N,K)-D5
      D11=TABLE(N,X)-D6
      D7=(PRESS(K-1)-PRESS(X))
      D8=PRESS(K-1)-P(I)
      D9=ABS((D8/D7)*(D10-D11))
      ANS(I)=D9+D10
90    IF (P(I).LT..001)P(I)=.00001
      MWS(I)=(.3685*TEMP(J)*ANS(I)/P(I))
91    CONTINUE
      WRITE(6,150)TEMP(J)
      WRITE(6,200)P(1),MWS(1),P(2),MWS(2),P(3),MWS(3)
      WRITE(6,200)P(4),MWS(4),P(5),MWS(5),P(6),MWS(6)
      WRITE(6,200)P(7),MWS(7),P(8),MWS(8),P(9),MWS(9)
      WRITE(6,250)P(10),MWS(10),P(11),MWS(11)
92    CONTINUE
      STOP
100   FORMAT(9F7.4,F7.3)
150   FORMAT(F12.6)
200   FORMAT  (6F12.6)
250   FORMAT  (4F12.6)
      END
$ENTRY
360.0  .01365 .54648 .95700 1.3681 5.5110 9.7130 13.976 60.13  112.7
396.0  .01241 .49666 .86860 1.2429 4.9960 8.7860 12.613 52.88  96.30
414.0  .01187 .47502 .83160 1.1985 4.7730 8.3880 12.031 49.99  90.19
432.0  .01138 .45519 .79680 1.1390 4.57[illegible] 8.0260 11.503 47.48  84.99
450.0  .01092 .43695 .76490 1.0930 4.3840 7.6940 11.021 45.18  80.48
468.0  .01050 .42011 .73540 1.0509 4.2120 7.3850 10.579 43.15  76.51
486.0  .01011 .40453 .70810 1.0117 4.0540 7.1080 10.172 41.31  72.98
504.0  .00975 .39006 .68270 0.9755 3.9070 6.8480  9.797 39.64  69.81
522.0  .00941 .37650 .65910 0.9417 3.7710 6.6170  9.449 38.12  66.95
540.0  .00910 .36403 .63710 0.9102 3.6440 6.3830  9.125 36.72  64.34
558.0  .00881 .35227 .61650 0.8808 3.5250 6.1720  8.824 35.42  61.96
576.0  .00853 .34126 .59720 0.8532 3.4140 5.9770  8.542 34.22  59.77
594.0  .00827 .33090 .57910 0.8273 3.3110 5.7940  8.278 33.11  57.74
612.0  .00802 .32117 .56210 0.8029 3.2120 5.6210  8.030 32.07  55.86
630.0  .00780 .31198 .54600 0.7800 3.1196 5.4590  7.797 31.10  54.11
720.0  .00683 .27297 .47770 0.6823 2.7277 4.7710  6.811 27.04  46.89
```

APPENDIX D: SAMPLE PROPERTY TABLE

```
$ENTRY
400.0                                                                        CAG 0010
0.0          .2484       100.0       .2534       200.0        .2571          CAG 0020
300.0        .2626       400.0       .2578       500.0        .2730          CAG 0030
600.0        .2779       700.0       .2842       800.0        .2962          CAG 0040
900.0        .3003       1000.0      .3060                1.E5          1.E5CAG 0050
410.0                                                                        CAG 0060
0.0          .2484       100.0       .2532       200.0        .2569          CAG 0070
300.0        .2621       400.0       .2672       500.0        .2721          CAG 0080
600.0        .2769       700.0       .2827       800.0        .2918          CAG 0090
900.0        .2976       1000.0      .3030                1.E5          1.E5CAG 0100
420.0                                                                        CAG 0110
0.0          .2484       100.0       .2531       200.0        .2566          CAG 0120
300.0        .2616       400.0       .2665       500.0        .2712          CAG 0130
600.0        .2758       700.0       .2815       800.0        .2894          CAG 0140
900.0        .2950       1000.0      .3000                1.E5          1.E5CAG 0150
430.0                                                                        CAG 0160
0.0          .2484       100.0       .2529       200.0        .2564          CAG 0170
300.0        .2612       400.0       .2658       500.0        .2704          CAG 0180
600.0        .2748       700.        .2801       800.0        .2869          CAG 0190
900.0        .2924       1000.0      .2970                1.E5          1.E5CAG 0200
440.0                                                                        CAG 0210
0.0          .2484       100.0       .2527       200.0        .2561          CAG 0220
300.         .2607       400.0       .2651       500.0        .2695          CAG 0230
600.0        .2737       700.0       .2787       800.0        .2847          CAG 0240
900.0        .2898       1000.0      .2942                1.E5          1.E5CAG 0250
450.0                                                                        CAG 0260
0.0          .2484       100.0       .2526       200.0        .2559          CAG 0270
300.0        .2602       400.0       .2645       500.0        .2686          CAG 0280
600.0        .2726       700.0       .2774       800.0        .2825          CAG 0290
900.0        .2872       1000.0      .2915                1.E5          1.E5CAG 0300
460.0                                                                        CAG 0310
0.0          .2484       100.0       .2524       200.0        .2556          CAG 0320
300.0        .2597       400.0       .2638       500.0        .2678          CAG 0330
600.0        .2716       700.0       .2759       800.0        .2804          CAG 0340
```

```
900.0     .2848     1000.0    .2838                   1.E5      1.E5CAG 0350
470.0                                                               CAG 0360
0.0       .2484     100.0     .2522     200.0     .2554             CAG 0370
300.0     .2594     400.0     .2631     500.0     .2668             CAG 0380
600.0     .2706     700.0     .2746     800.0     .2786             CAG 0390
900.0     .2826     1000.0    .2863                   1.E5      1.E5CAG 0400
+.480000E+03                                                        CAG 0410
+.000000E+00+.248400E-00+.100000E+03+.252000E-00+.200000E+03+.255200E-00CAG 0420
+.300000E+03+.258300E-00+.400000E+03+.262500E-00+.500000E+03+.266000E-00CAG 0430
+.600000E+03+.269500E-00+.700000E+03+.273200E-00+.800000E+03+.276000E-00CAG 0440
+.900000E+03+.280500E-00+.100000E+04+.284100E-00+.100000E+06+.100000E+06CAG 0450
+.490000E+03                                                        CAG 0460
+.000000E-00+.248400E-00+.100000E+03+.251900E-00+.200000E+03+.254900E-00CAG 0470
+.300000E+03+.258300E-00+.400000E+03+.261700E-00+.500000E+03+.265000E-00CAG 0480
+.600000E+03+.268400E-00+.700000E+03+.271700E-00+.800000E+03+.275200E-00CAG 0490
+.900000E+03+.278500E-00+.100000E+04+.281800E-00+.100000E+06+.100000E+06CAG 0500
+.500000E+03                                                        CAG 0510
+.000000E+00+.248400E+00+.100000E+03+.251700E+00+.200000E+03+.254700E+00CAG 0520
+.300000E+03+.257800E+00+.400000E+03+.261000E+00+.500000E+03+.264200E+00CAG 0530
+.600000E+03+.267300E+00+.700000E+03+.270500E+00+.800000E+03+.273700E+00CAG 0540
+.900000E+03+.276800E+00+.100000E+04+.280000E+00+.100000E+06+.100000E+06CAG 0550
+.510000E+03                                                        CAG 0560
+.000000E+00+.248400E+00+.100000E+03+.251600E+00+.200000E+03+.254400E+00CAG 0570
+.300000E+03+.257300E+00+.400000E+03+.260400E+00+.500000E+03+.263300E+00CAG 0580
+.600000E+03+.266400E+00+.700000E+03+.269400E+00+.800000E+03+.272400E+00CAG 0590
+.900000E+03+.275400E+00+.100000E+04+.278300E+00+.100000E+06+.100000E+06CAG 0600
+.520000E+03                                                        CAG 0610
+.000000E+00+.248400E+00+.100000E+03+.251400E+00+.200000E+03+.254200E+00CAG 0620
+.300000E+03+.256900E+00+.400000E+03+.259800E+00+.500000E+03+.262600E+00CAG 0630
+.600000E+03+.265400E+00+.700000E+03+.268300E+00+.800000E+03+.271200E+00CAG 0640
+.900000E+03+.274000E+00+.100000E+04+.275300E+00+.100000E+06+.100000E+06CAG 0650
+.530000E+03                                                        CAG 0660
+.000000E+00+.248400E+00+.100000E+03+.251200E+00+.200000E+03+.253900E+00CAG 0670
+.300000E+03+.256500E+00+.400000E+03+.259100E+00+.500000E+03+.261800E+00CAG 0680
+.600000E+03+.264600E+00+.700000E+03+.267200E+00+.800000E+03+.270100E+00CAG 0690
+.900000E+03+.272800E+00+.100000E+04+.275500E+00+.100000E+06+.100000E+06CAG 0700
+.540000E+03                                                        CAG 0710
+.000000E+00+.248400E+00+.100000E+03+.251100E+00+.200000E+03+.253600E+00CAG 0720
+.300000E+03+.256100E+00+.400000E+03+.258800E+00+.500000E+03+.261300E+00CAG 0730
+.600000E+03+.263900E+00+.700000E+03+.266500E+00+.800000E+03+.269100E+00CAG 0740
+.900000E+03+.271700E+00+.100000E+04+.274200E+00+.100000E+06+.100000E+06CAG 0750
+.550000E+03                                                        CAG 0760
+.000000E+00+.248400E+00+.100000E+03+.250900E+00+.200000E+03+.253400E+00CAG 0770
+.300000E+03+.255800E+00+.400000E+03+.258300E+00+.500000E+03+.260700E+00CAG 0780
+.600000E+03+.263200E+00+.700000E+03+.265700E+00+.800000E+03+.268100E+00CAG 0790
+.900000E+03+.270600E+00+.100000E+04+.273000E+00+.100000E+06+.100000E+06CAG 0800
+.560000E+03                                                        CAG 0810
+.000000E+00+.248400E+00+.100000E+03+.250700E+00+.200000E+03+.253200E+00CAG 0820
+.300000E+03+.255600E+00+.400000E+03+.257900E+00+.500000E+03+.260200E+00CAG 0830
+.600000E+03+.262600E+00+.700000E+03+.264900E+00+.800000E+03+.267200E+00CAG 0840
+.900000E+03+.269600E+00+.100000E+04+.272000E+00+.100000E+06+.100000E+06CAG 0850
+.570000E+03+.100000E+01                                            CAG 0860
+.000000E+00+.248400E+00+.100000E+03+.250500E+00+.200000E+03+.253000E+00CAG 0870
+.300000E+03+.255400E+00+.400000E+03+.257500E+00+.500000E+03+.259700E+00CAG 0880
+.600000E+03+.261900E+00+.700000E+03+.264100E+00+.800000E+03+.266400E+00CAG 0890
+.900000E+03+.268500E+00+.100000E+04+.270800E+00+.100000E+06+.100000E+06CAG 0900
+.000000E+00                                                        CBG 0910
+.000000E+00+.460000E+00+.100000E+04+.460000E+00+.100000E+06+.100000E+06CBG 0920
+.100000E+04+.100000E+01                                            CBG 0930
+.000000E+00+.460000E+00+.100000E+04+.460000E+00+.100000E+06+.100000E+06CBG 0940
400.0                                                               WAG 0950
0.0       28.010    100.0     28.210    200.0     28.376            WAG 0960
300.0     28.540    400.0     28.855    500.0     29.120            WAG 0970
600.0     29.244    700.0     29.552    800.0     29.590            WAG 0980
900.0     29.779    1000.0    29.940                  1.E5      1.E5WAG 0990
410.0                                                               WAG 1000
0.0       28.010    100.0     28.198    200.0     28.355            WAG 1010
300.0     28.544    400.0     28.703    500.0     29.032            WAG 1020
600.0     29.150    700.0     29.420    800.0     29.462            WAG 1030
900.0     29.615    1000.0    29.780                  1.E5      1.E5WAG 1040
420.0                                                               WAG 1050
0.0       28.010    100.0     28.186    200.0     28.332            WAG 1060
```

```
300.0          28.508         400.0          28.730         500.0            28.942        WAG  1070
600.0          29.055         700.0          29.292         800.0            29.331        WAG  1080
900.0          29.460         1000.0         29.600                    1.E5           1.E5*WAG  1090
430.0                                                                                  WAG  1100
0.0            28.010         100.0          28.175         200.0            28.310        WAG  1110
300.0          28.472         400.0          28.659         500.0            28.953        WAG  1120
600.0          28.958         700.0          29.147         800.0            29.200        WAG  1130
900.0          29.312         1000.0         29.425                    1.E5           1.E5*WAG  1140
440.0                                                                                  WAG  1150
0.0            28.010         100.0          28.163         200.0            28.288        WAG  1160
300.0          28.436         400.0          28.675         500.0            28.765        WAG  1170
600.0          28.863         700.0          29.012         800.0            29.070        WAG  1180
900.0          29.165         1000.0         29.255                    1.E5           1.E5*WAG  1190
450.0                                                                                  WAG  1200
0.0            28.010         100.0          28.151         200.0            28.266        WAG  1210
300.0          28.400         400.0          28.543         500.0            28.680        WAG  1220
600.0          28.768         700.0          28.882         800.0            28.940        WAG  1230
900.0          29.020         1000.0         29.090           .        1.E5           1.E5*WAG  1240
460.0                                                                                  WAG  1250
0.0            28.010         100.0          28.140         200.0            28.244        WAG  1260
300.0          28.363         400.0          28.482         500.0            28.595        WAG  1270
600.0          28.677         700.0          28.760         800.0            28.817        WAG  1280
900.0          28.880         1000.0         28.840                    1.E5           1.E5*WAG  1290
470.0                                                                                  WAG  1300
0.0            28.010         100.0          28.128         200.0            28.222        WAG  1310
300.0          28.327         400.0          28.422         500.0            28.517        WAG  1320
600.0          28.587         700.0          28.648         800.0            28.700        WAG  1330
900.0          28.750         1000.0         28.700                    1.E5           1.E5*WAG  1340
+.480000E+03                                                                           WAG  1350
+.000000E+00+.280100E+02+.100000E+03+.281160E+02+.200000E+03+.282100E+02WAG  1360
+.300000E+03+.282860E+02+.400000E+03+.283750E+02+.500000E+03+.284460E+02WAG  1370
+.600000E+03+.285040E+02+.700000E+03+.285520E+02+.800000E+03+.285900E+02WAG  1380
+.900000E+03+.286270E+02+.100000E+04+.285180E+02+.100000E+06+.100000E+06WAG  1390
+.490000E+03                                                                           WAG  1400
+.000000E+00+.280100E+02+.100000E+03+.281040E+02+.200000E+03+.281800E+02WAG  1410
+.300000E+03+.282520E+02+.400000E+03+.283180E+02+.500000E+03+.283730E+02WAG  1420
+.600000E+03+.284240E+02+.700000E+03+.284560E+02+.800000E+03+.284880E+02WAG  1430
+.900000E+03+.285130E+02+.100000E+04+.285380E+02+.100000E+06+.100000E+06WAG  1440
+.500000E+03                                                                           WAG  1450
+.000000E+00+.280100E+02+.100000E+03+.280920E+02+.200000E+03+.281550E+02WAG  1460
+.300000E+03+.282160E+02+.400000E+03+.282680E+02+.500000E+03+.283100E+02WAG  1470
+.600000E+03+.283500E+02+.700000E+03+.283650E+02+.800000E+03+.283360E+02WAG  1480
+.900000E+03+.284120E+02+.100000E+04+.284280E+02+.100000E+06+.100000E+06WAG  1490
+.510000E+03                                                                           WAG  1500
+.000000E+00+.280100E+02+.100000E+03+.280800E+02+.200000E+03+.281320E+02WAG  1510
+.300000E+03+.281840E+02+.400000E+03+.282220E+02+.500000E+03+.282530E+02WAG  1520
+.600000E+03+.282820E+02+.700000E+03+.282980E+02+.800000E+03+.283130E+02WAG  1530
+.900000E+03+.283200E+02+.100000E+04+.283300E+02+.100000E+06+.100000E+06WAG  1540
+.520000E+03                                                                           WAG  1550
+.000000E+00+.280100E+02+.100000E+03+.280680E+02+.200000E+03+.281120E+02WAG  1560
+.300000E+03+.281500E+02+.400000E+03+.281800E+02+.500000E+03+.282020E+02WAG  1570
+.600000E+03+.282200E+02+.700000E+03+.282300E+02+.800000E+03+.282350E+02WAG  1580
+.900000E+03+.282350E+02+.100000E+04+.282350E+02+.100000E+06+.100000E+06WAG  1590
+.530000E+03                                                                           WAG  1600
+.000000E+00+.280100E+02+.100000E+03+.280580E+02+.200000E+03+.280900E+02WAG  1610
+.300000E+03+.281200E+02+.400000E+03+.281430E+02+.500000E+03+.281560E+02WAG  1620
+.600000E+03+.281640E+02+.700000E+03+.281680E+02+.800000E+03+.281630E+02WAG  1630
+.900000E+03+.281560E+02+.100000E+04+.281480E+02+.100000E+06+.100000E+06WAG  1640
+.540000E+03                                                                           WAG  1650
+.000000E+00+.280100E+02+.100000E+03+.280480E+02+.200000E+03+.280700E+02WAG  1660
+.300000E+03+.280920E+02+.400000E+03+.281080E+02+.500000E+03+.281140E+02WAG  1670
+.600000E+03+.281120E+02+.700000E+03+.281100E+02+.800000E+03+.280960E+02WAG  1680
+.900000E+03+.280800E+02+.100000E+04+.280640E+02+.100000E+06+.100000E+06WAG  1690
+.550000E+03                                                                           WAG  1700
+.000000E+00+.280100E+02+.100000E+03+.280400E+02+.200000E+03+.280550E+02WAG  1710
+.300000E+03+.280680E+02+.400000E+03+.280750E+02+.500000E+03+.280730E+02WAG  1720
+.600000E+03+.280560E+02+.700000E+03+.280540E+02+.800000E+03+.280350E+02WAG  1730
+.900000E+03+.280150E+02+.100000E+04+.279920E+02+.100000E+06+.100000E+06WAG  1740
+.560000E+03                                                                           WAG  1750
+.000000E+00+.280100E+02+.100000E+03+.280320E+02+.200000E+03+.280440E+02WAG  1760
+.300000E+03+.280480E+02+.400000E+03+.280430E+02+.500000E+03+.280360E+02WAG  1770
+.600000E+03+.280260E+02+.700000E+03+.280040E+02+.800000E+03+.279840E+02WAG  1780
```

```
+.900000E+03+.279560E+02+.100000E+04+.279320E+02+.100000E+06+.100000E+06WAG  1790
+.570000E+03+.100000E+01                                                WAG  1800
+.000000E+00+.280100E+02+.100000E+03+.280300E+02+.200000E+03+.280400E+02WAG  1810
+.300000E+03+.280320E+02+.400000E+03+.280130E+02+.500000E+03+.280000E+02WAG  1820
+.600000E+03+.279900E+02+.700000E+03+.279560E+02+.800000E+03+.279450E+02WAG  1830
+.900000E+03+.279100E+02+.100000E+04+.278860E+02+.100000E+06+.100000E+06WAG  1840
+.000000E+00                                                            WBG  1850
+.000000E+00+.180160E+02+.100000E+04+.180160E+02+.100000E+06+.100000E+06WBG  1860
+.100000E+04+.100000E+01                                                WBG  1870
+.000000E+00+.180160E+02+.100000E+04+.180160E+02+.100000E+06+.100000E+06WBG  1880
+.000000E+00+.248400E+00+.100000E+04+.248400E+00+.100000E+06+.100000E+06CAL  1890
+.492000E+03+.100740E+01+.495000E+03+.100600E+01+.500000E+03+.100400E+01CBL  1900
+.505000E+03+.100250E+01+.510000E+03+.100130E+01+.515000E+03+.100040E+01CBL  1910
+.520000E+03+.999500E+00+.525000E+03+.919100E+00+.530000E+03+.998700E+00CBL  1920
+.535000E+03+.998400E+00+.540000E+03+.998200E+00+.545000E+03+.998000E+00CBL  1930
+.550000E+03+.998000E+00+.555000E+03+.997300E+00+.560000E+03+.998000E+00CBL  1940
+.565000E+03+.998000E+00+.570000E+03+.998100E+00+.100000E+06+.100000E+06CBL  1950
+.000000E-00+.000000E-00+.100000E+04+.000000E-00+.100000E+06+.100000E+06LA   1960
+.492000E+03+.107250E+04+.492500E+03+.107000E+04+.493000E+03+.106900E+04LB  1970
+.494000E+03+.106760E+04+.496000E+03+.105550E+04+.500000E+03+.106280E+04LB  1980
+.570000E+03+.102440E+04+.100000E+06+.100000E+06                        LB   1990
400.0        .015         410.0        .017         420.0        .019        PBO  2000
430.0        .021         440.0        .026         450.0        .035        PBO  2010
460.0        .045         470.0        .055         480.0        .065        PBO  2020
+.492000E+03+.900000E-01+.500000E+03+.118000E-00+.505000E+03+.114000E-00PBO  2030
+.510000E+03+.176000E-00+.515000E+03+.222000E-00+.520000E+03+.254000E-00PBO  2040
+.525000E+03+.304000E-00+.530000E+03+.361000E-00+.535000E+03+.426000E-00PBO  2050
+.540000E+03+.502000E-00+.545000E+03+.590000E-00+.550000E+03+.692000E-00PBO  2060
+.555000E+03+.812000E-00+.560000E+03+.950000E-00+.565000E+03+.110000E+01PBO  2070
+.570000E+03+.127200E+01+.100000E+06+.100000E+06                        PBO  2080
400.0        62.418       410.0        62.418       420.0        62.418      ROAL 2090
430.0        62.418       440.0        62.418       450.0        62.418      ROAL 2100
460.0        62.419       470.0        62.418       480.0        62.418      ROAL 2110
+.492000E+03+.624180E+02+.494000E+03+.624220E+02+.496000E+03+.624250E+02ROAL 2120
+.498000E+03+.624260E+02+.500000E+03+.624260E+02+.502000E+03+.624250E+02ROAL 2130
+.504000E+03+.624230E+02+.506000E+03+.624200E+02+.508000E+03+.624150E+02ROAL 2140
+.510000E+03+.624100E+02+.512000E+03+.624030E+02+.514000E+03+.623950E+02ROAL 2150
+.516000E+03+.623870E+02+.518000E+03+.623770E+02+.520000E+03+.623670E+02ROAL 2160
+.522000E+03+.623550E+02+.524000E+03+.623430E+02+.526000E+03+.623300E+02ROAL 2170
+.528000E+03+.623160E+02+.530000E+03+.623020E+02+.532000E+03+.622860E+02ROAL 2180
+.534000E+03+.622700E+02+.536000E+03+.622530E+02+.538000E+03+.622350E+02ROAL 2190
+.540000E+03+.622170E+02+.542000E+03+.621980E+02+.544000E+03+.621780E+02ROAL 2200
+.546000E+03+.621570E+02+.548000E+03+.621360E+02+.550000E+03+.621140E+02ROAL 2210
+.552000E+03+.620910E+02+.554000E+03+.620680E+02+.556000E+03+.620440E+02ROAL 2220
+.558000E+03+.620200E+02+.560000E+03+.619950E+02+.562000E+03+.619700E+02ROAL 2230
+.564000E+03+.619430E+02+.566000E+03+.619160E+02+.568000E+03+.618880E+02ROAL 2240
+.570000E+03+.618610E+02+.100000E+06+.100000E+06                        ROAL 2250
+.492000E+03+.624180E+02+.494000E+03+.624220E+02+.496000E+03+.624250E+02ROBL 2260
+.498000E+03+.624260E+02+.500000E+03+.624260E+02+.502000E+03+.624250E+02ROBL 2270
+.504000E+03+.624230E+02+.506000E+03+.624200E+02+.508000E+03+.624150E+02ROBL 2280
+.510000E+03+.624100E+02+.512000E+03+.624030E+02+.514000E+03+.623950E+02ROBL 2290
+.516000E+03+.623870E+02+.518000E+03+.623770E+02+.520000E+03+.623670E+02ROBL 2300
+.522000E+03+.623550E+02+.524000E+03+.623430E+02+.526000E+03+.623300E+02ROBL 2310
+.528000E+03+.623160E+02+.530000E+03+.623020E+02+.532000E+03+.622860E+02ROBL 2320
+.534000E+03+.622700E+02+.536000E+03+.622530E+02+.538000E+03+.622350E+02ROBL 2330
+.540000E+03+.622170E+02+.542000E+03+.621980E+02+.544000E+03+.621780E+02ROBL 2340
+.546000E+03+.621570E+02+.548000E+03+.621360E+02+.550000E+03+.621140E+02ROBL 2350
+.552000E+03+.620910E+02+.554000E+03+.620680E+02+.556000E+03+.620440E+02ROBL 2360
+.558000E+03+.620200E+02+.560000E+03+.619950E+02+.562000E+03+.619700E+02ROBL 2370
+.564000E+03+.619430E+02+.566000E+03+.619160E+02+.568000E+03+.618880E+02ROBL 2380
+.570000E+03+.618610E+02+.100000E+06+.100000E+06                        ROBL 2390
400.0        .01177       410.0        .01202       420.0        .01225      KAG  2400
430.0        .01250       440.0        .01275       450.0        .01297      KAG  2410
460.0        .01320       470.0        .01344       480.0        .01584      KAG  2420
570.0        .01594       1.         +51.         +5                         KAG  2430
400.0        .00698       410.0        .00722       420.0        .00745      KBG  2440
430.0        .00770       440.0        .00793       450.0        .00818      KBG  2450
460.0        .00840       470.0        .00864       480.0        .00888      KBG  2460
+.492000E+03+.920000E-02+.500000E+03+.934000E-02+.510000E+03+.958000E-02KBG  2470
+.520000E+03+.980000E-02+.530000E+03+.100500E-01+.540000E+03+.103000E-01KBG  2480
+.550000E+03+.105500E-01+.560000E+03+.107900E-01+.570000E+03+.110400E-01KBG  2490
+.100000E+06+.100000E+06                                                KBG  2500
```

```
400.0          4.33           410.0          4.33           420.0          4.33           VIAL2510
430.0          4.33           440.0          4.33           450.0          4.33           VIAL2520
460.0          4.33           470.0          4.33           480.0          4.33           VIAL2530
+.492000E+03+.433000E+01+.500000E+03+.374000E+01+.510000E+03+.316000E+01VIAL2540
+.520000E+03+.272000E+01+.530000E+03+.237000E+01+.540000E+03+.208000E+01VIAL2550
+.550000E+03+.195000E+01+.560000E+03+.165000E+01+.570000E+03+.150000E+01VIAL2560
+.100000E+06+.100000E+06                                                VIAL2570
+.492000E+03+.433000E+01+.500000E+03+.374000E+01+.510000E+03+.316000E+01VIBL2580
+.520000E+03+.272000E+01+.530000E+03+.237000E+01+.540000E+03+.208000E+01VIBL2590
+.550000E+03+.185000E+01+.560000E+03+.165000E+01+.570000E+03+.150000E+01VIBL2600
+.100000E+06+.100000E+06                                                VIBL2610
400.0          .03445         410.0          .03505         420.0          .03568         VIAG2620
430.0          .03630         440.0          .03693         450.0          .03755         VIAG2630
460.0          .03818         470.0          .03880         480.0          .03940         VIAG2640
490.0          .04005         500.0          .04065         510.0          .04130         VIAG2650
520.0          .04190         530.0          .04255         540.0          .04315         VIAG2660
550.0          .04375         560.0          .04435         570.0          .04495         VIAG2670
1.         + 51.          +5                                                            VIAG2680
400.0          .01900         410.0          .01940         420.0          .01980         VIBG2690
430.0          .02020         440.0          .02060         450.0          .02100         VIBG2700
460.0          .02145         470.0          .02190         480.0          .02235         VIBG2710
+.492000E+03+.232000E-01+.500000E+03+.234000E-01+.510000E+03+.237500E-01VIBG2720
+.520000E+03+.241000E-01+.530000E+03+.245000E-01+.540000E+03+.249000E-01VIBG2730
+.550000E+03+.253000E-01+.560000E+03+.258000E-01+.570000E+03+.262500E-01VIBG2740
+.100000E+06+.100000E+06                                                VIBG2750
+.492000E+03+.756000E+02+.530000E+03+.726000E+02+.550000E+03+.708000E+02SIG 2760
+.570000E+03+.690000E+02+.100000E+06+.100000E+06                        SIG 2770
```

```
APRIL 15, 1980     1               NOZZLE D, 2 MPA                           920      1
    1       0       0     30     30     30     1
-0.3           20.0           0.0            0.0            5.28
       .89E-60.0             -0.3            28.02          18.02          208.0
1010.0          0.05          290.0          537.0          537.0          20.0
20.0            0.005         0.005          0.0004         0.003          0.1
10 IN. NOZZLE
  .290001+03   .000000       .289564+03    .138144+00    .288580+03    .276288+00
  .286616+03   .414432+00    .283025+03    .552576+00    .276898+03    .690720+00
  .266995+03   .828864+00    .252206+03    .967008+00    .236879+03    .110515+01
  .222415+03   .124330+01    .208777+03    .138144+01    .195929+03    .151958+01
  .183834+03   .165773+01    .172458+03    .179587+01    .161766+03    .193402+01
  .151728+03   .207216+01    .142310+03    .221030+01    .133482+03    .234845+01
  .125216+03   .248659+01    .117431+03    .262474+01    .110251+03    .276289+01
  .103500+03   .290102+01    .972006+02    .303917+01    .913291+02    .317731+01
  .858612+02   .331546+01    .807742+02    .345360+01    .760453+02    .359174+01
  .716549+02   .372989+01    .675810+02    .386803+01    .638046+02    .400618+01
  .603069+02   .414432+01    .570700+02    .428246+01    .540765+02    .442061+01
  .513102+02   .455875+01    .487553+02    .469690+01    .463969+02    .483504+01
  .442206+02   .497319+01    .422129+02    .511133+01    .403611+02    .524947+01
  .386527+02   .538762+01    .370764+02    .552576+01    .356211+02    .566391+01
  .342765+02   .580205+01    .330328+02    .594019+01    .318810+02    .607834+01
  .308124+02   .621648+01    .298189+02    .635463+01    .288931+02    .649277+01
  .280280+02   .663091+01    .272169+02    .676906+01    .264540+02    .690720+01
  .257135+02   .704535+01    .250505+02    .718349+01    .244000+02    .732163+01
  .237779+02   .745978+01    .231803+02    .759792+01    .226035+02    .773607+01
  .220445+02   .787421+01    .215003+02    .801235+01    .209684+02    .815050+01
  .204466+02   .828864+01    .199329+02    .842679+01    .194257+02    .856493+01
  .189235+02   .870307+01    .184252+02    .884122+01    .179296+02    .897936+01
  .174360+02   .911751+01    .169438+02    .925565+01    .164525+02    .939379+01
  .159617+02   .953194+01    .154712+02    .967008+01    .149807+02    .980823+01
  .144904+02   .994637+01    .140000+02    .100845+02    .100000+06    .100000+06
```

APPENDIX F: SAMPLE 140PC CALIBRATION PROGRAM

```
10    DIM X(15,100),Sum(15),Mean(15),Sum2(15),Sd(15)
30    N=10
40    FOR I=1 TO N
50       OUTPUT 709;"AI1VT1"
60       ENTER 709:X(1,I)
70       OUTPUT 709:"AI2VT1"
80       ENTER 709:X(2,I)
90       OUTPUT 709:"AI3VT1"
100      ENTER 709;X(3,I)
110      OUTPUT 709;"AI4VT1"
120      ENTER 709;X(4,I)
130      OUTPUT 709;"AI5VT1"
140      ENTER 709:X(5,I)
150      OUTPUT 709;"AI6VT1"
160      ENTER 709:X(6,I)
170      OUTPUT 709;"AI7VT1"
180      ENTER 709:X(7,I)
190      OUTPUT 709;"AI8VT1"
200      ENTER 709;X(8,I)
210      OUTPUT 709;"AI9VT1"
220      ENTER 709;X(9,I)
230      OUTPUT 709;"AI16VT1"
240      ENTER 709;X(10,I)
250      OUTPUT 709;"AI11VT1"
260      ENTER 709;X(11,I)
261      OUTPUT 709;"AI12VT1"
262      ENTER 709;X(12,I)
263      OUTPUT 709;"AI13VT1"
264      ENTER 709;X(13.I)
267      OUTPUT 709;"AI17VT1"
268      ENTER 709;X(14,I)
270   NEXT I
```

```
280   PRINT "                          CHANNELS"
290   PRINT "    1       2       3       4       5       6       7       8"
300   !
310   PRINT "____________________________________________________________
"
320   PRINT
330   FOR I=1 TO N
340      PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I),X(4,I),X(5,I),X(6,I),X(7,I),
X(8,I)
350   NEXT I
360   PRINT
370   PRINT "                          CHANNEL"
380   PRINT "    9      10      11      12      13      17"
390   PRINT "____________________________________________________________
"
400   FOR I=1 TO N
410      PRINT USING "DD.DDDD";X(9,I),X(10,I),X(11,I),X(12,I),X(13,I),X(14,I)
411   NEXT I
413   PRINT
414   PRINT "                         MEAN   ","         STANDARD DEVIATION"
415   PRINT "_______________________________________________________"
420   PRINT
440   FOR J=1 TO 14
450      Sum(J)=0
460      FOR I=1 TO N
470         Sum(J)=Sum(J)+X(J,I)
480      NEXT I
490      Mean(J)=Sum(J)/N
510   NEXT J
512   FOR J=1 TO 14
513      FOR I=1 TO N
515        Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
516      NEXT I
518      Sd(J)=SQR(Sum2(J)/(N-1))
519      IF J=14 THEN GOTO 523
521   PRINT "channel   ";J,Mean(J),"   ",Sd(J)
522   GOTO 525
523   PRINT "CHANNAL   ";J+3,Mean(J),"   ",Sd(J)
525   NEXT J
526   END
```

APPENDIX G: SAMPLE OUTPUT TO CALIBRATION PROGRAM

THIS DATA IS FOR A PRESSURE OF 0 PSI

CHANNELS

1	2	3	4	5	6	7	8
1.6588	1.8301	1.7702	1.6914	1.8429	1.7485	1.7900	1.8098
1.6589	1.8305	1.7705	1.6922	1.8431	1.7484	1.7901	1.8101
1.6598	1.8308	1.7715	1.6931	1.8446	1.7500	1.7918	1.8120
1.6605	1.8318	1.7717	1.6935	1.8444	1.7499	1.7916	1.8117
1.6603	1.8317	1.7722	1.6931	1.8446	1.7497	1.7917	1.8117
1.6598	1.8315	1.7716	1.6928	1.8439	1.7495	1.7909	1.8112
1.6596	1.8310	1.7712	1.6925	1.8437	1.7494	1.7909	1.8110
1.6597	1.8310	1.7714	1.6925	1.8441	1.7494	1.7910	1.8112
1.6593	1.8311	1.7712	1.6923	1.8438	1.7496	1.7907	1.8114
1.6594	1.8313	1.7709	1.6927	1.8438	1.7496	1.7906	1.8109

CHANNEL

9	10	11	12	13	17
1.7941	1.7381	1.7211	1.8335	-.0119	14.8960
1.7946	1.7389	1.7221	1.8336	-.0119	14.9000
1.7961	1.7397	1.7239	1.8353	-.0119	14.9090
1.7958	1.7400	1.7232	1.8341	-.0119	14.9060
1.7960	1.7401	1.7237	1.8351	-.0119	14.9030
1.7957	1.7402	1.7236	1.8347	-.0119	14.9000
1.7955	1.7388	1.7233	1.8340	-.0119	14.8990
1.7959	1.7394	1.7226	1.8342	-.0119	14.9020
1.7958	1.7398	1.7233	1.8338	-.0119	14.9020
1.7954	1.7394	1.7231	1.8341	-.0119	14.9000

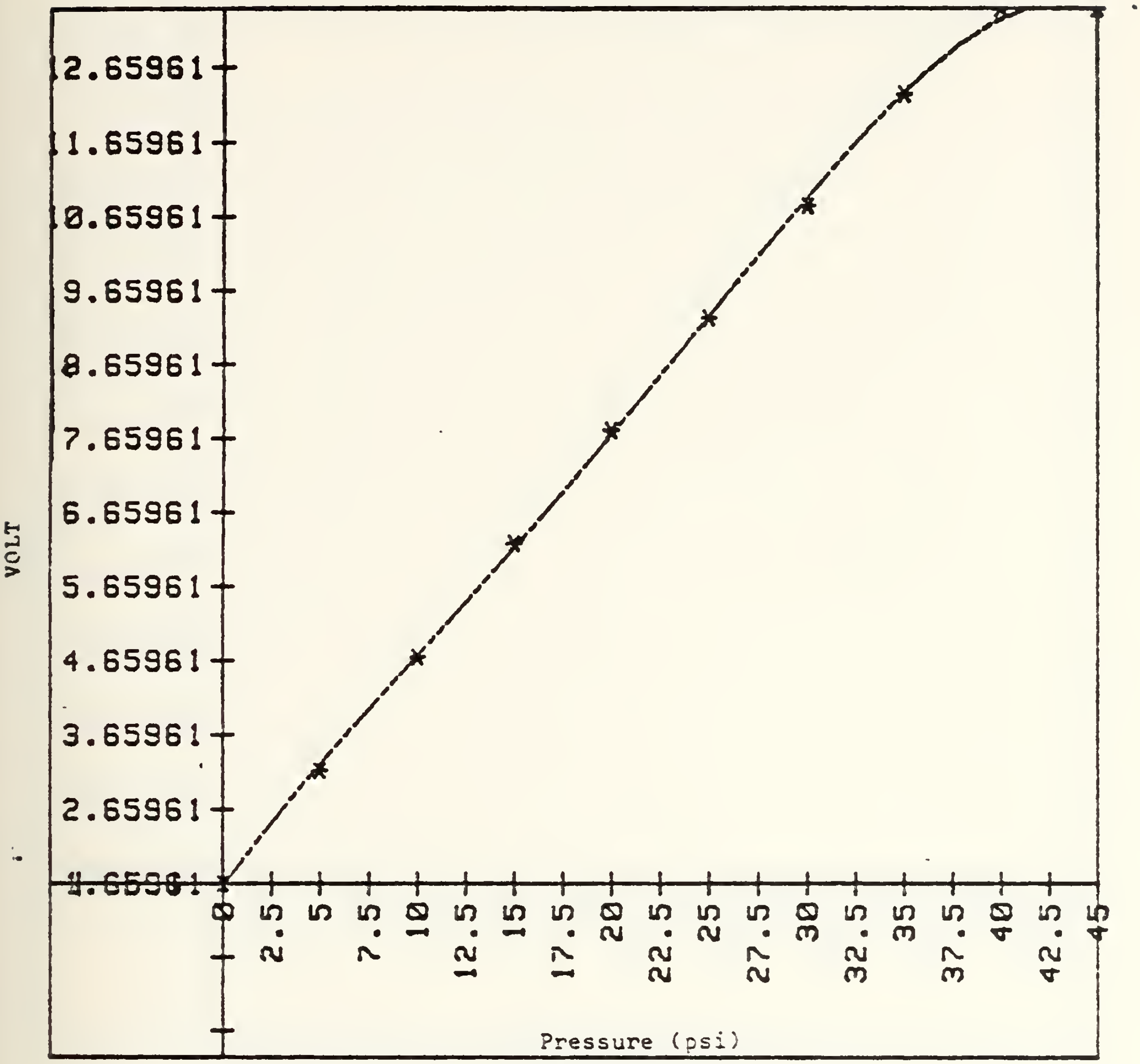
		MEAN	STANDARD DEVIATION
channel	1	1.65961	.000542524961023
channel	2	1.83108	.000528730134904
channel	3	1.77124	.000587272414548
channel	4	1.69261	.000583952052826
channel	5	1.84389	.000574359546703
channel	6	1.7494	.000537483849887
channel	7	1.79093	.0006254775953
channel	8	1.8111	.000697614984549
channel	9	1.79549	.000647130417905
channel	10	1.73944	.000668663675633
channel	11	1.72299	.000847807630172
channel	12	1.83424	.000607728009338
channel	13	-.0118729	8.1846740246E-6
channal	17	14.9017	.00368329562575

APPENDIX H: SAMPLE 200PC CALIBRATION PROGRAM

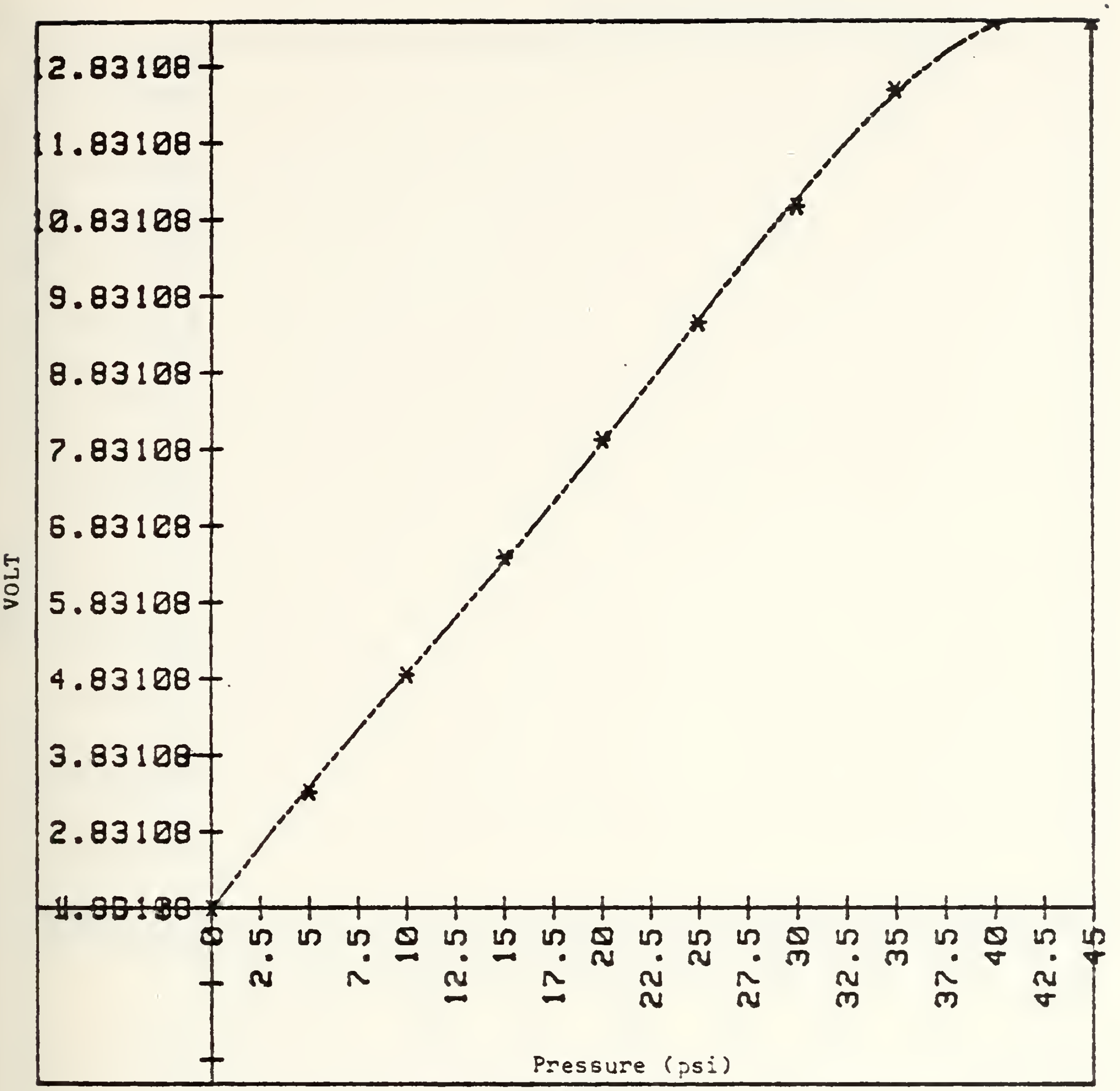
```
PRINT "THIS PROGRAM IS USED TO CALIBRATE 100 PSI PRESSURE TRANSDUCERS."
PRINT "ENTER THE AMOUNT OF READINGS YOU WISH THE PROGRAM TO AVERAGE"
DIM X(11,100),Sum(11),Mean(11),Sum2(11),Sd(11)
PRINT
INPUT N
Y=0
FOR T=1 TO 11
  PRINT
  PRINT
  PRINT "THIS RUN IS FOR A PRESSURE OF";Y;"PSI"
  PRINT "__________________________________________"
  PRINT
  PRINT " ONCE THE PRESSURE IS SET AT";Y;"PSI"
  PRINT "PUSH THE CONTINUE BUTTON AND WAIT FOR DATA."
  Y=Y+10
  PAUSE
FOR I=1 TO N
   OUTPUT 709;"AI12VT1"
   ENTER 709;X(1,I)
   OUTPUT 709;"AI14VT1"
   ENTER 709;X(2,I)
   OUTPUT 709;"AI15VT1"
   ENTER 709;X(3,I)
NEXT I
```

```
PRINT "                          CHANNELS"
PRINT "     1,        2          3  "
PRINT "________________________________________________________________"
PRINT
FOR I=1 TO N
   PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I)
NEXT I
PRINT
PRINT "                                MEAN  ","         STANDARD DEVIATION"
PRINT "____________________________________________________________________________"
PRINT
FOR J=1 TO 3
   Sum(J)=0
   FOR I=1 TO N
      Sum(J)=Sum(J)+X(J,I)
   NEXT I
   Mean(J)=Sum(J)/N
NEXT J
FOR J=1 TO 3
   FOR I=1 TO N
     Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
   NEXT I
   Sd(J)=SQR(Sum2(J)/(N-1))
PRINT "channel   ";J,Mean(J),"    ",Sd(J)
NEXT J
PRINT
PRINT
PRINT
NEXT T
END
```

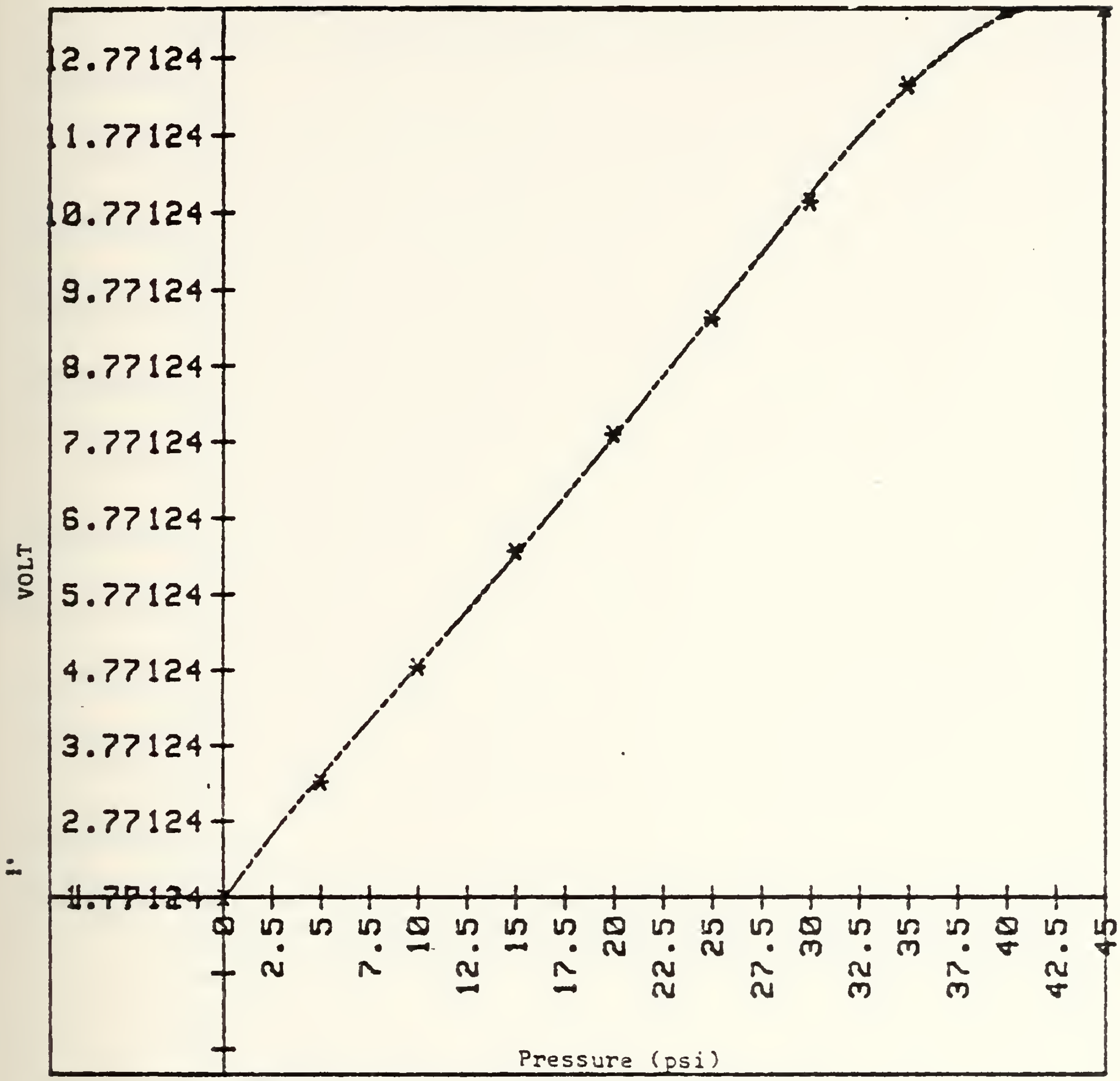
APPENDIX I: CALIBRATION PLOT OF PRESSURE TRANSDUCERS



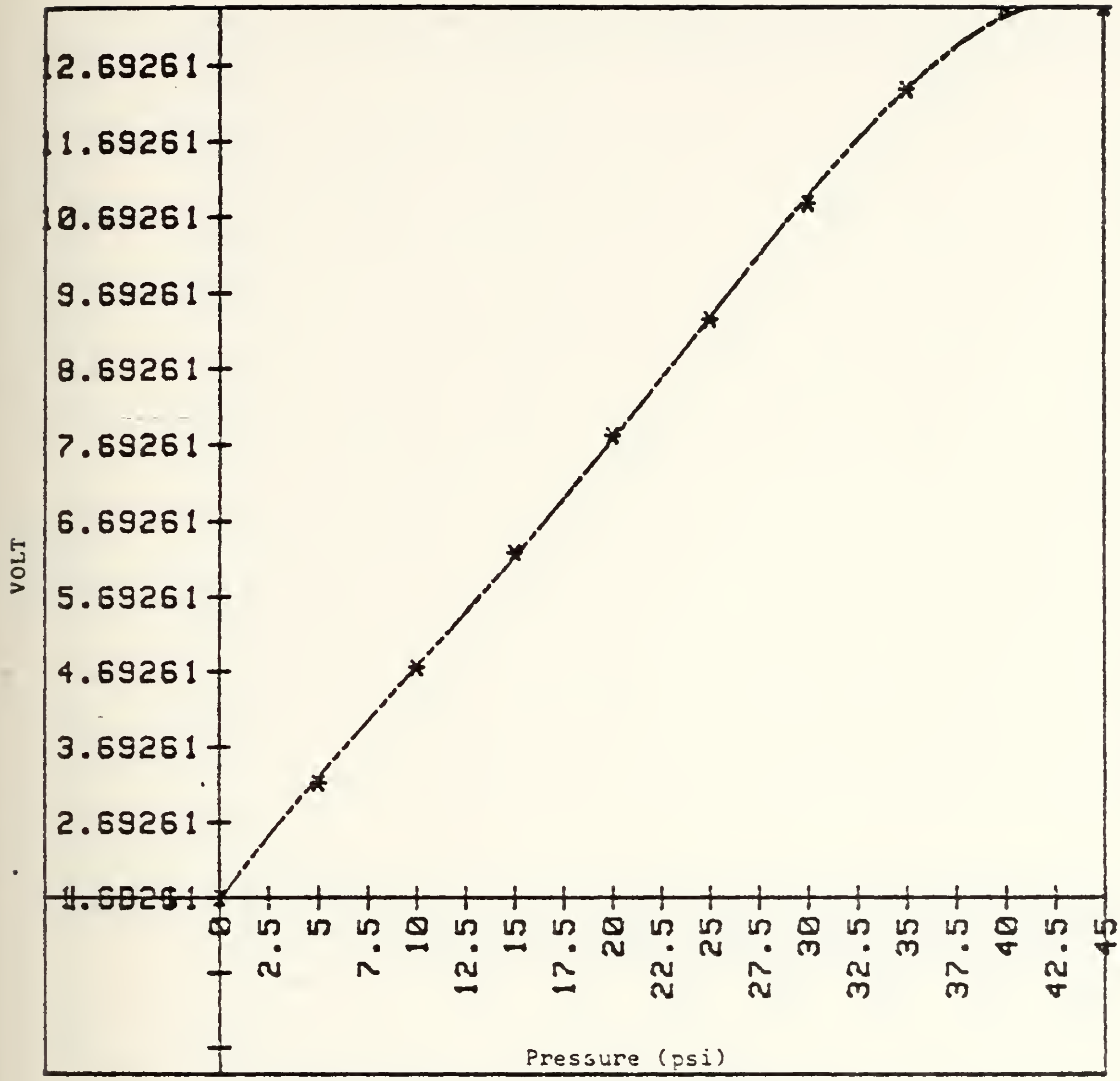
Calibration Plot of Pressure Transducer A



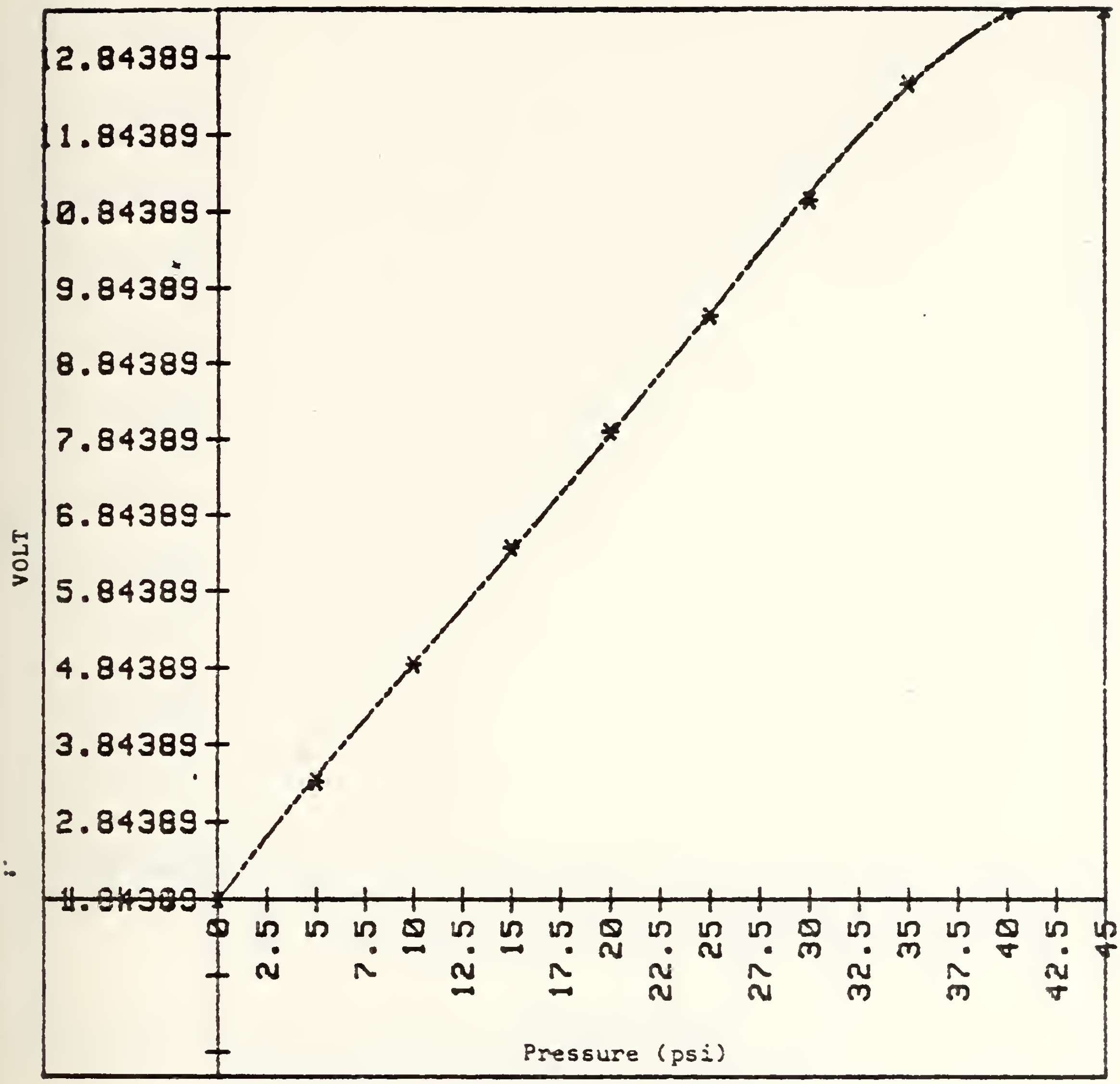
Calibration Plot of Pressure Transducer B



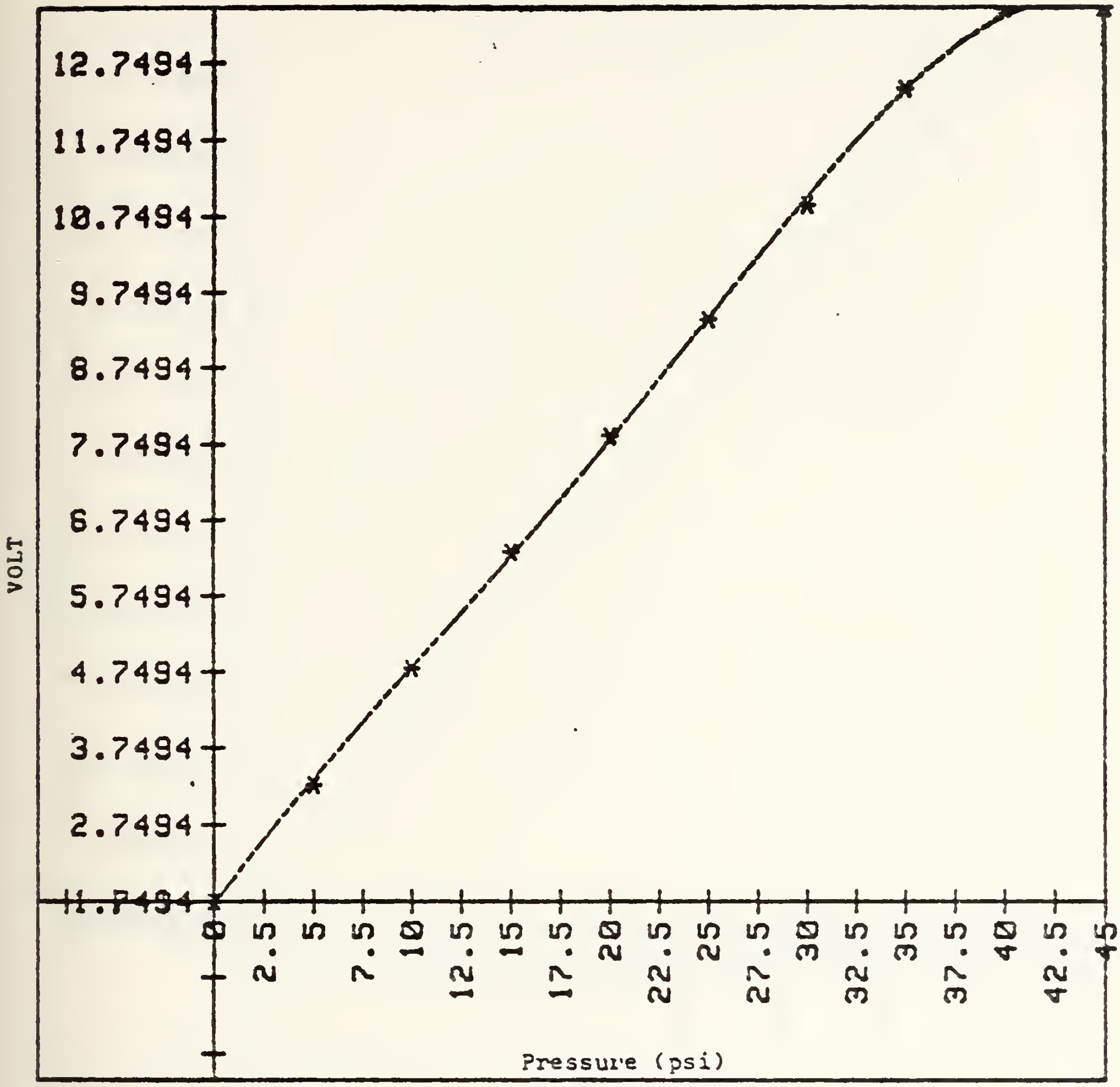
Calibration Plot of Pressure Transducer C



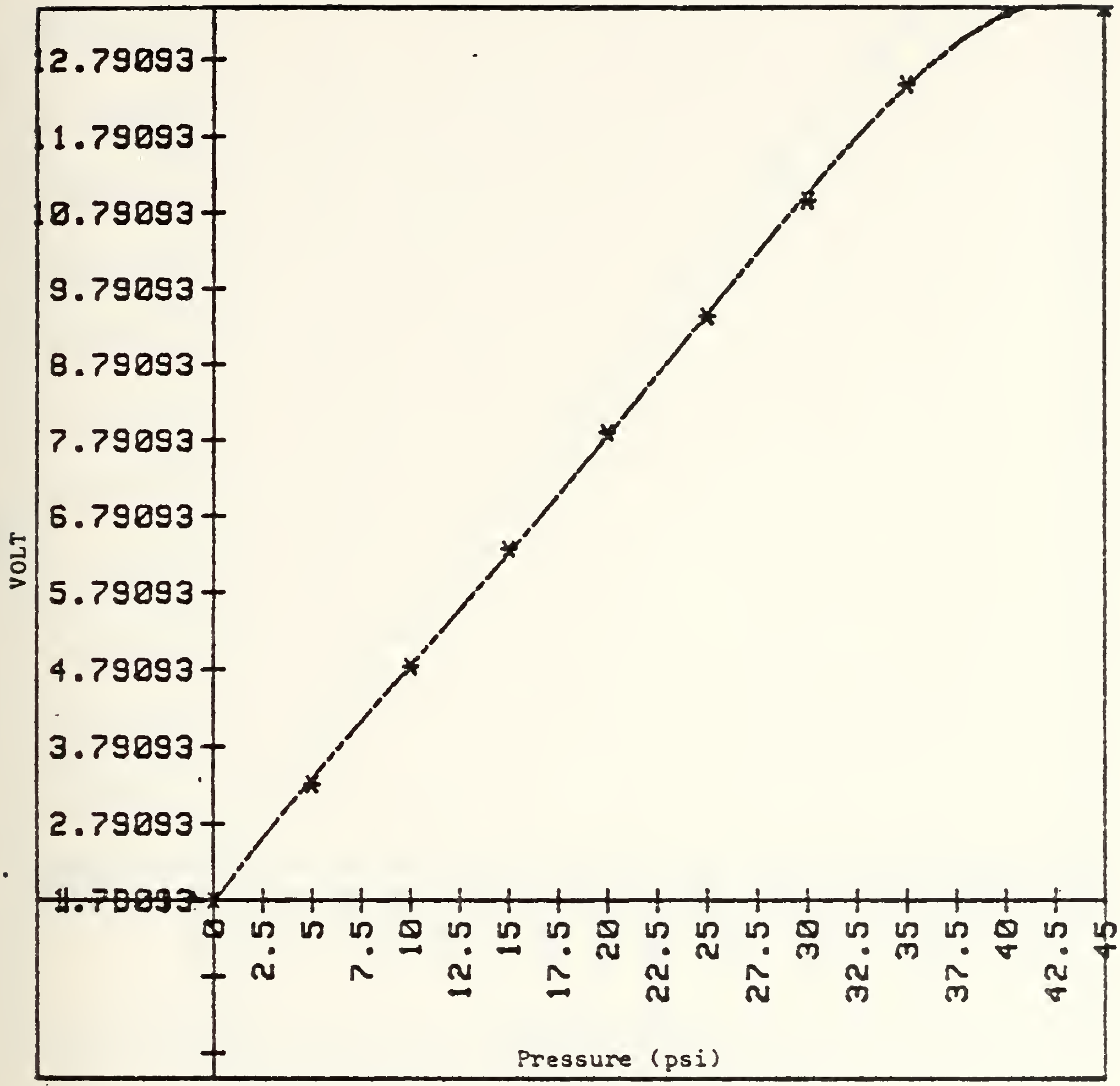
Calibration Plot of Pressure Transducer D



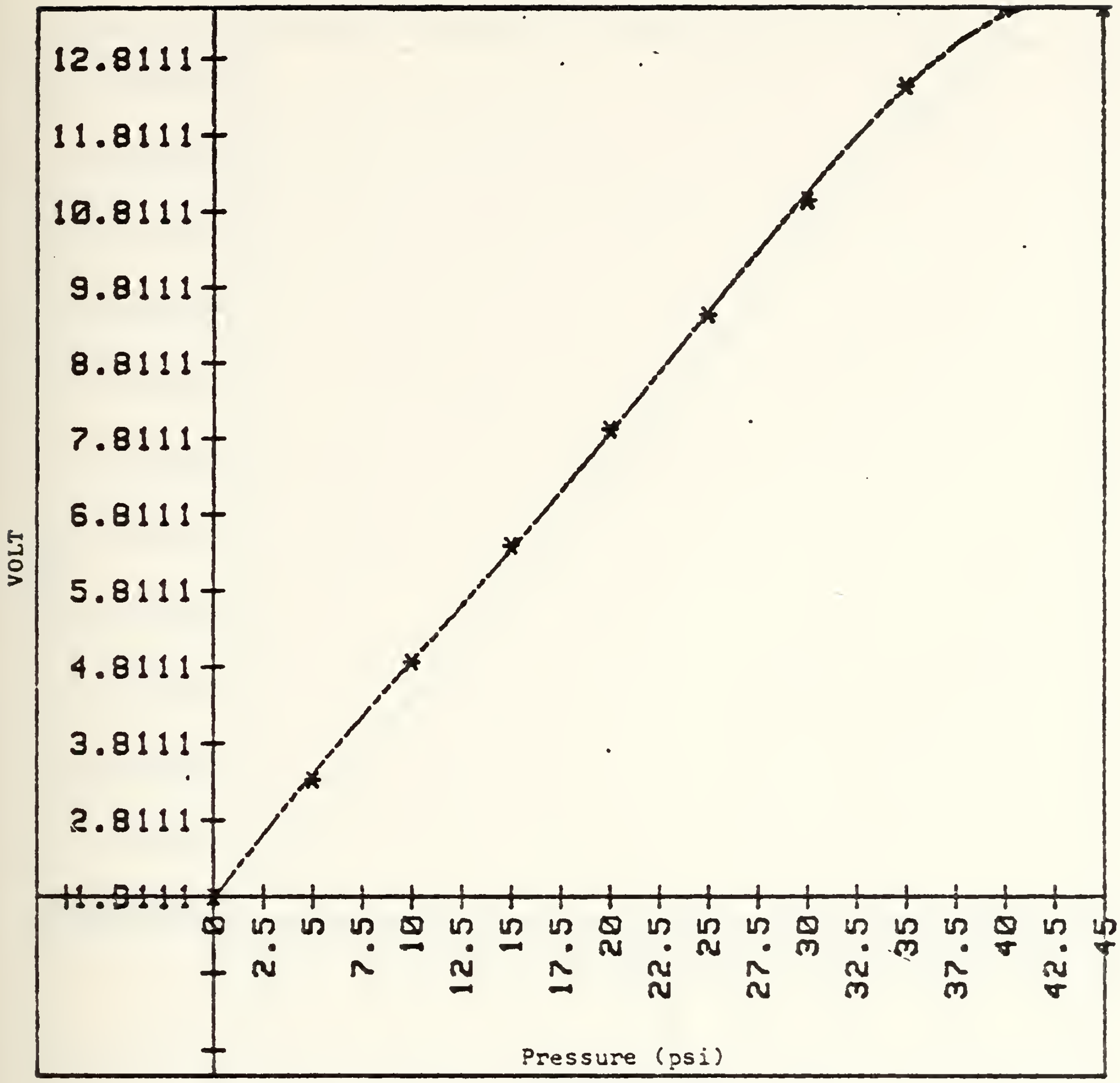
Calibration Plot of Pressure Transducer E



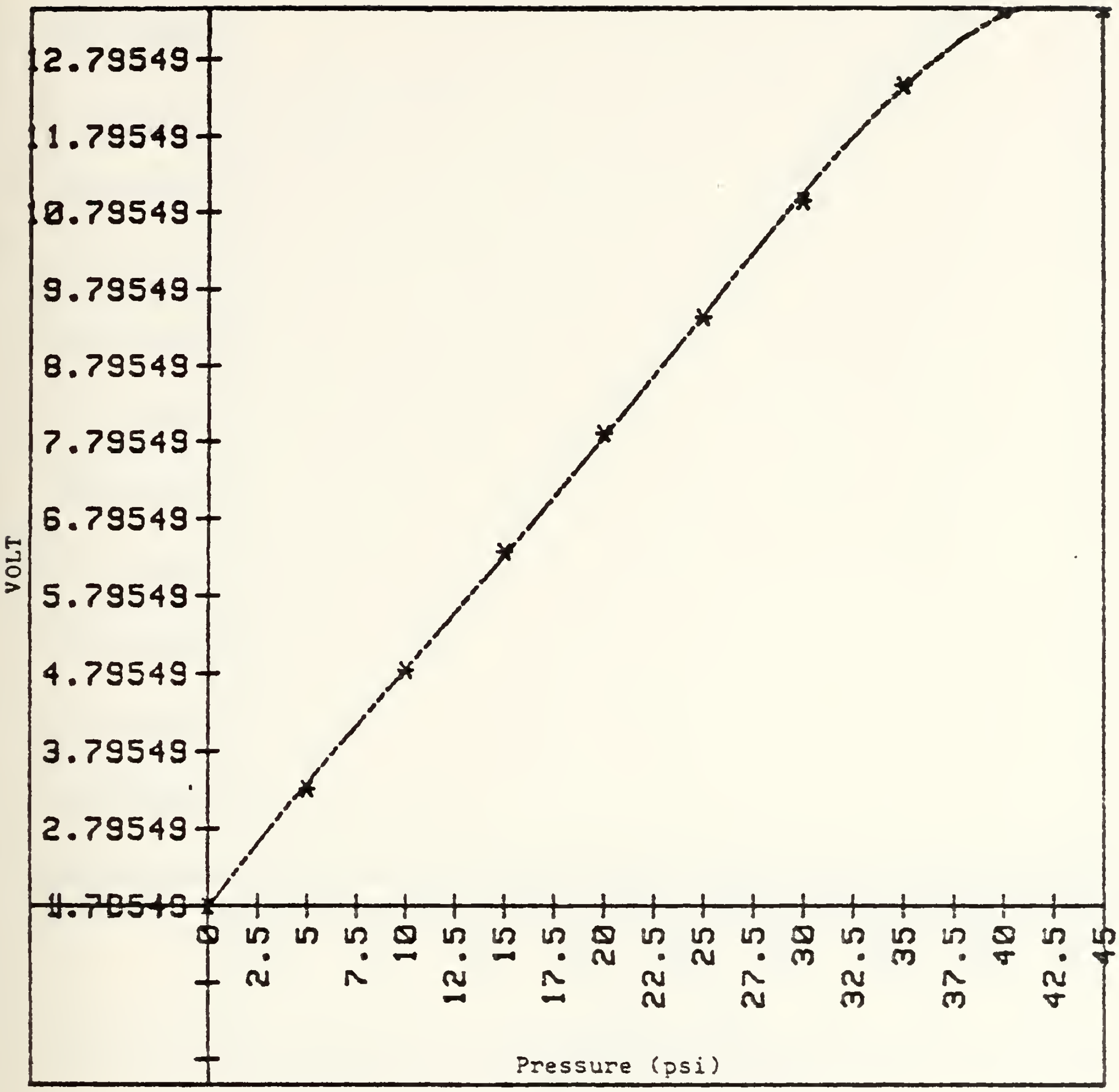
Calibration Plot of Pressure Transducer F



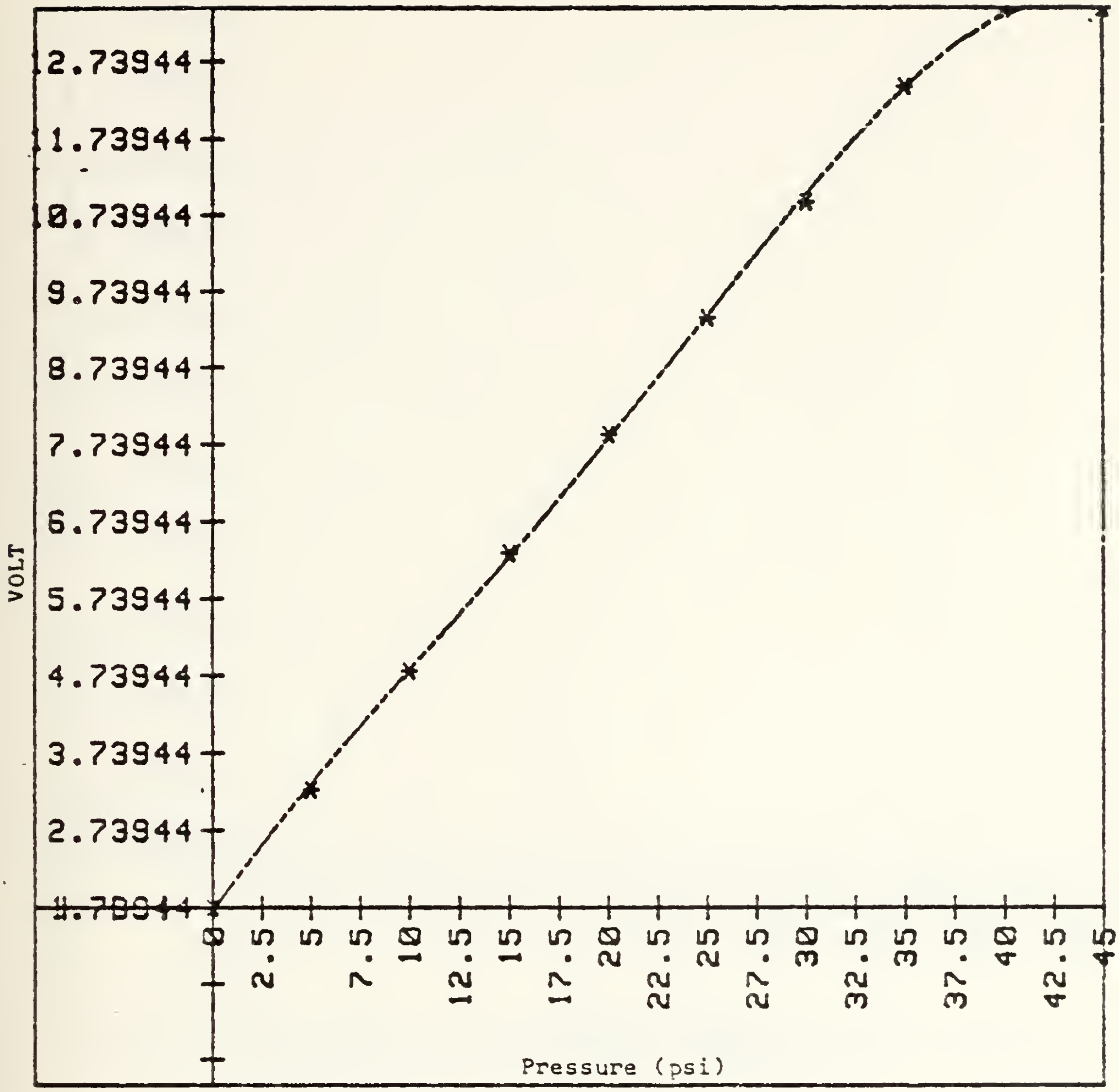
Calibration Plot of Pressure Transducer G



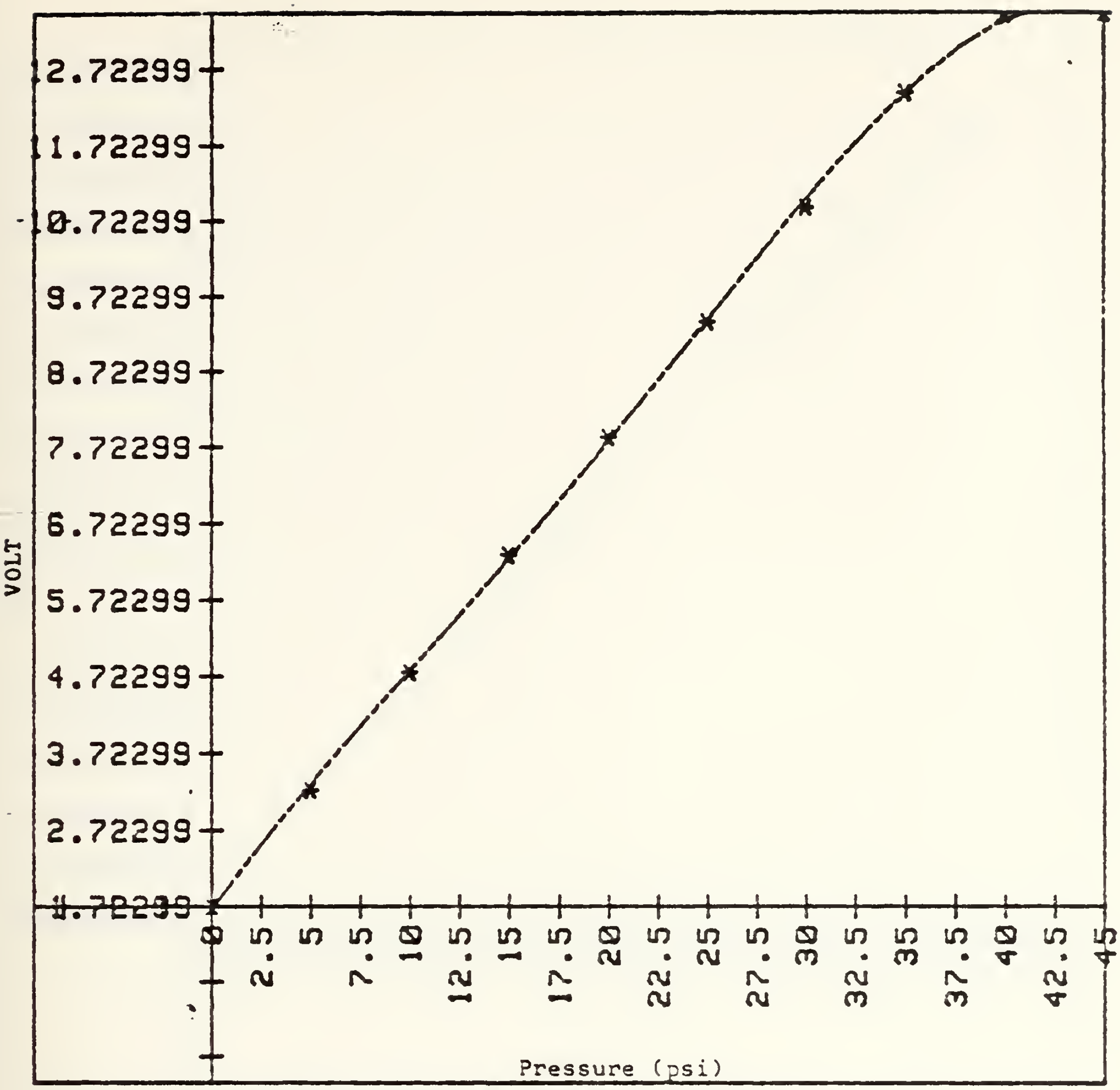
Calibration Plot of Pressure Transducer H



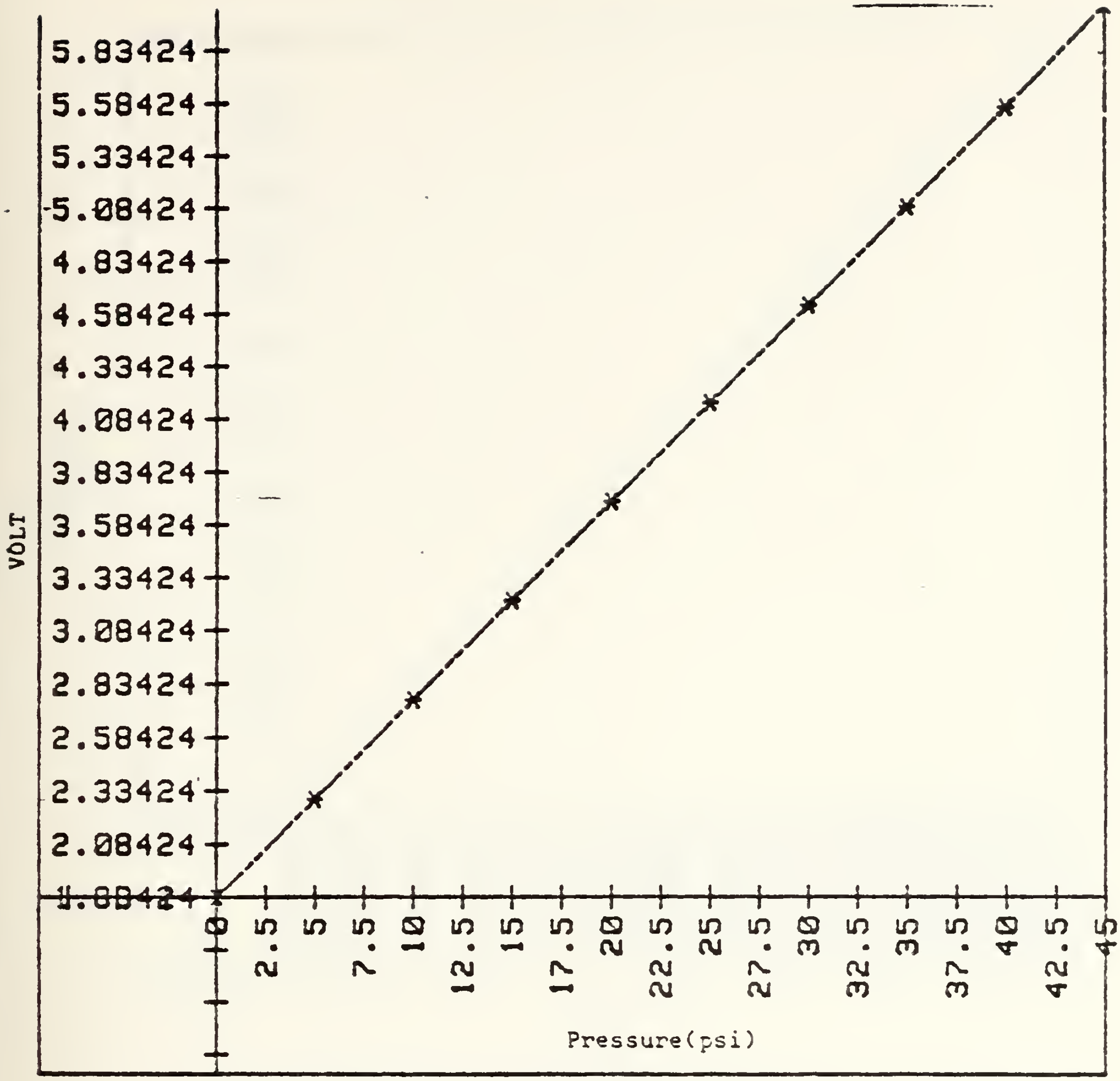
Calibration Plot of Pressure Transducer I



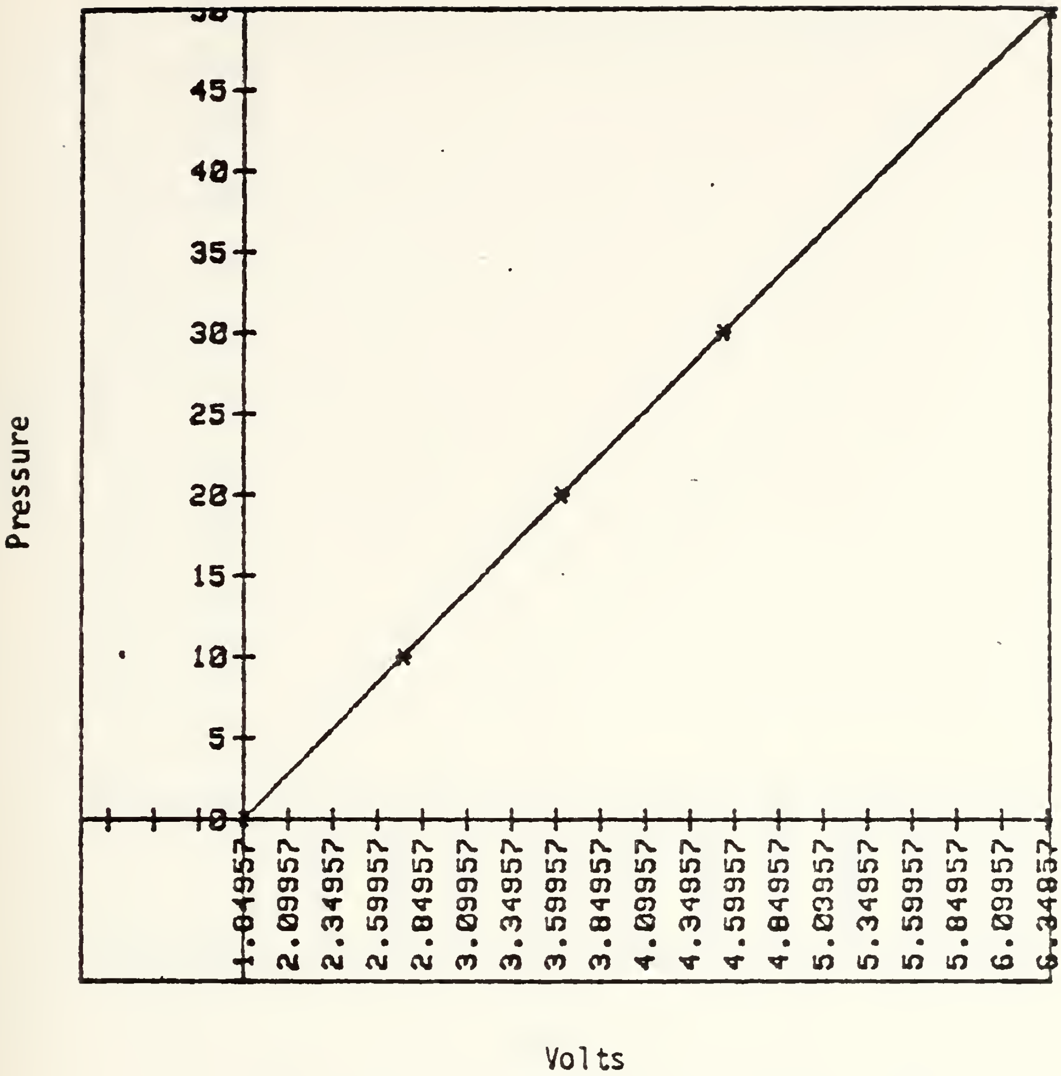
Calibration Plot of Pressure Transducer J



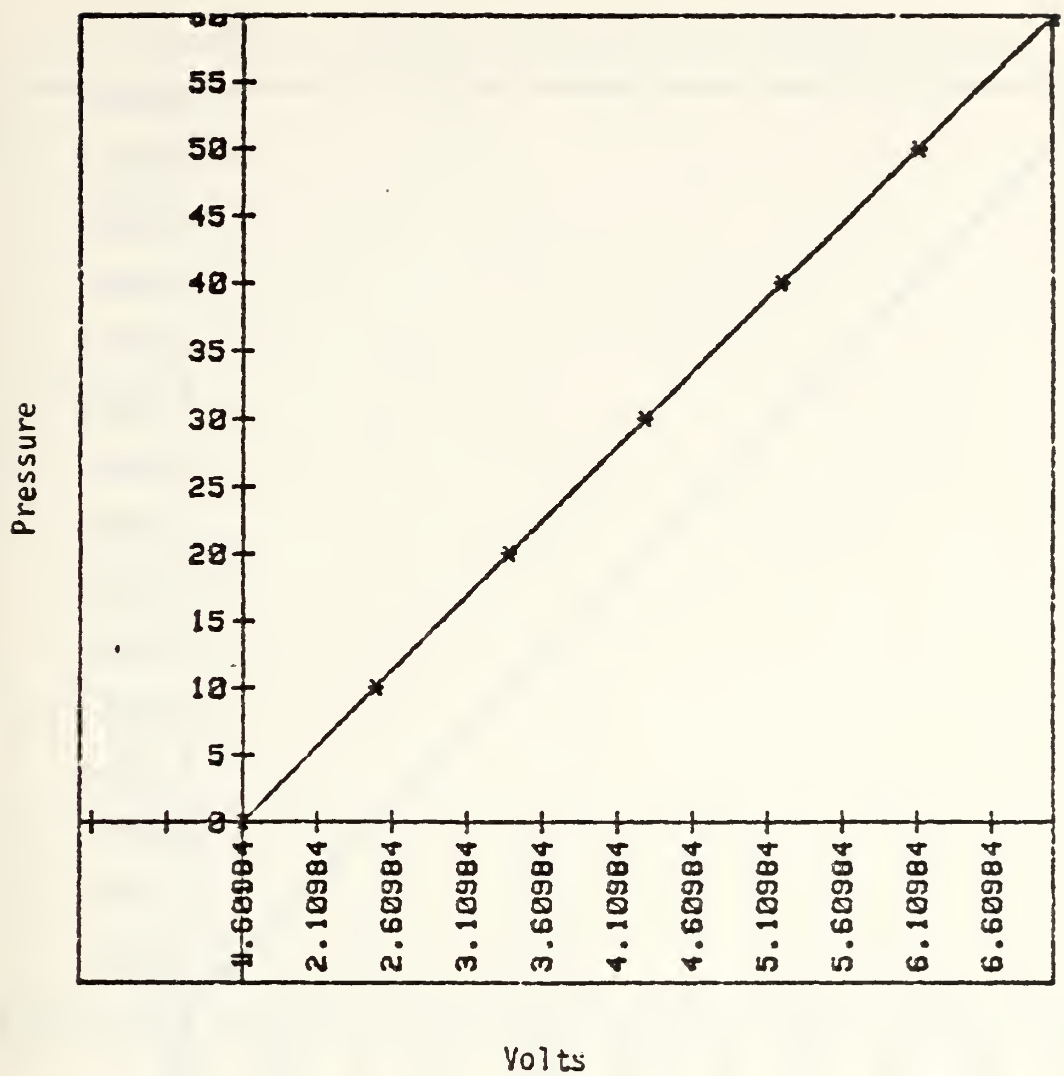
Calibration Plot of Pressure Transducer K



Calibration Plot of Pressure Transducer L

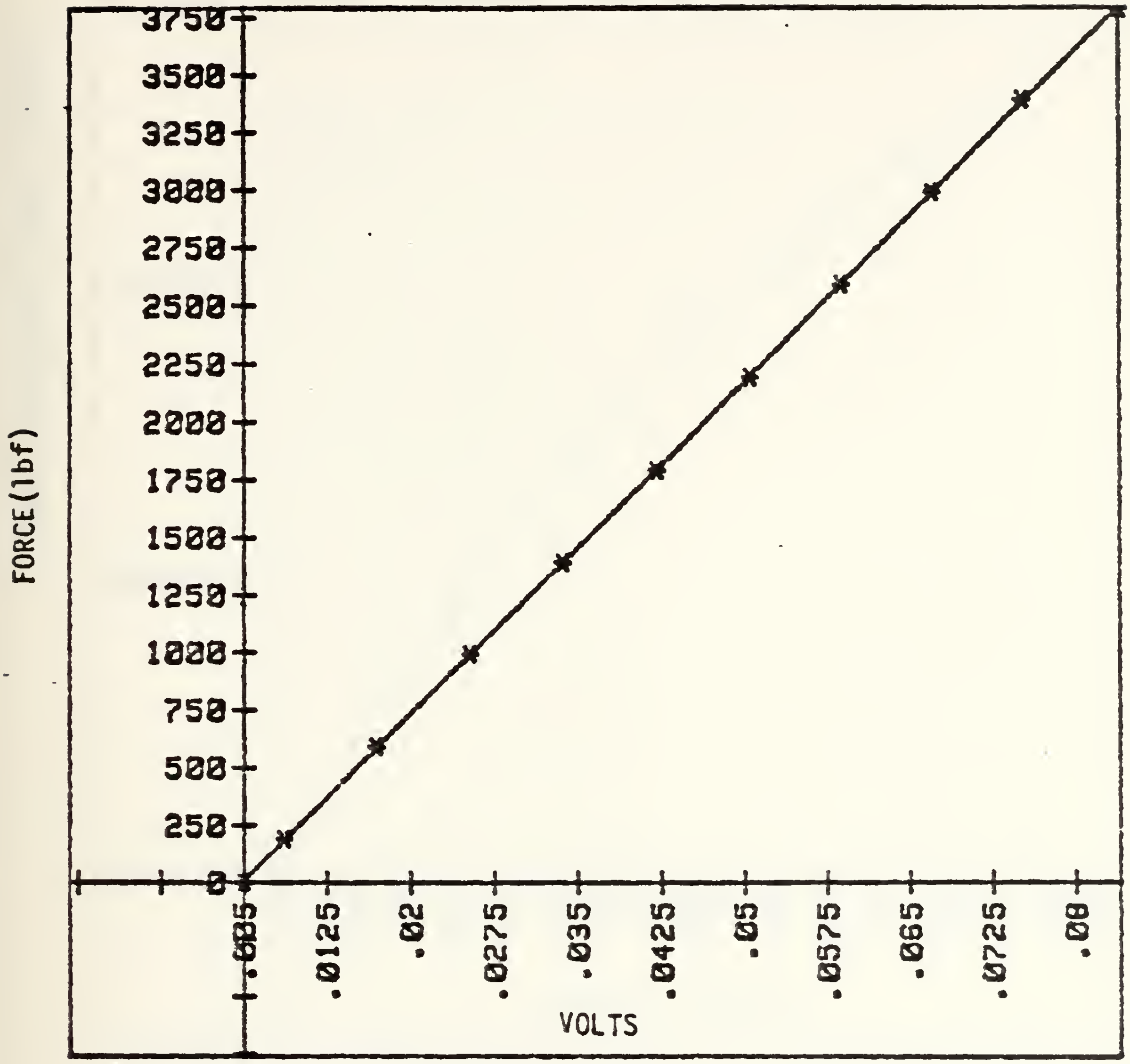


Calibration plot of pressure Transducer 0



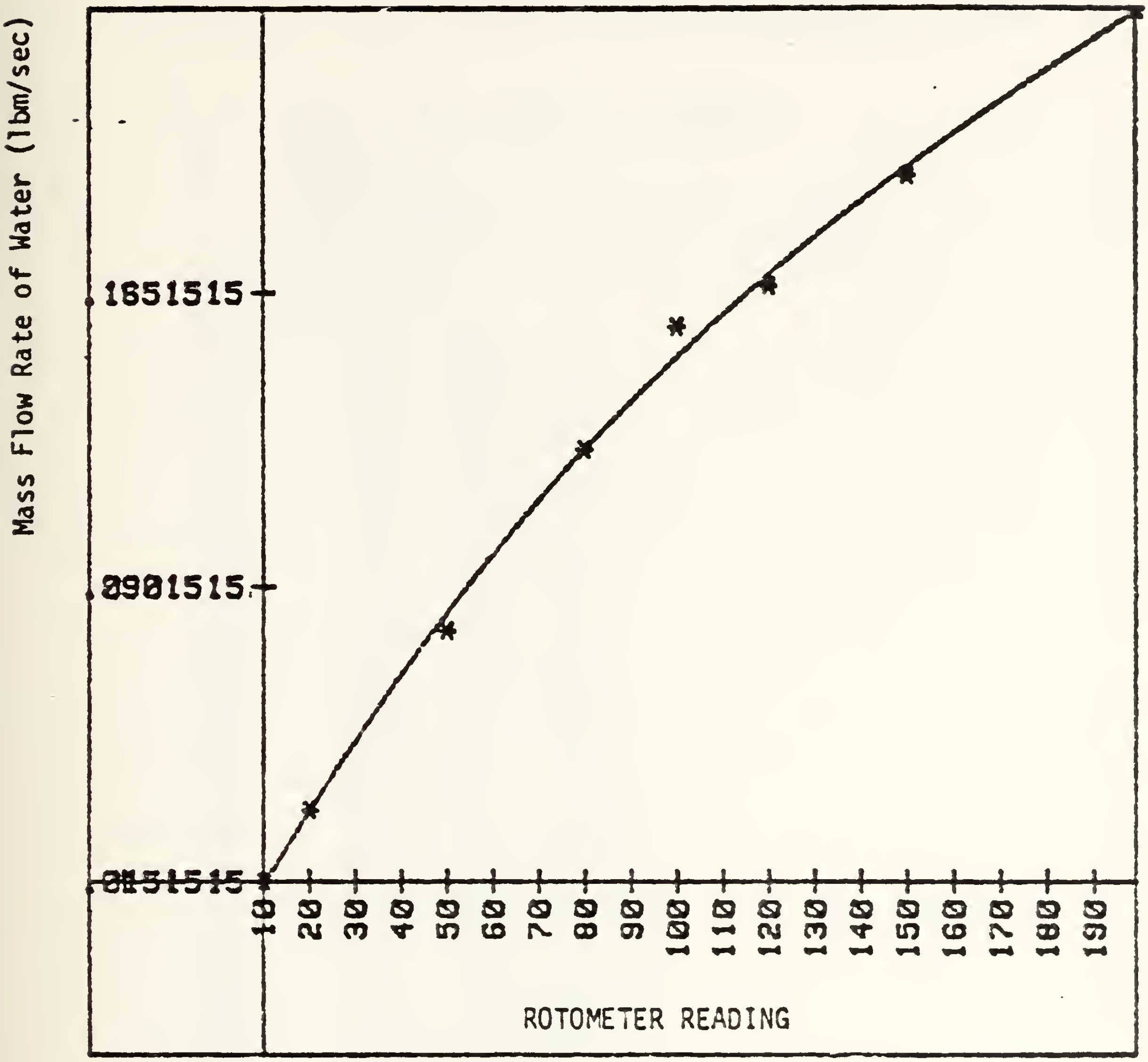
Calibration Plot of Pressure Transducer P

APPENDIX J: CALIBRATION PLOT FOR FORCE-BLOCK



Calibration Plot For Force-Block

APPENDIX K: CALIBRATION PLOT FOR ROTOMETER



Calibration Plot for Rotometer

APPENDIX L: DATA ACQUISITION AND ANALYSIS PROGRAM

```
3      PRINT "INPUT ROTOMETER READING"
4      INPUT Rr
5      PRINT Rr
7      DIM A(14),B(14),C(14),Dist(14),D(14)
8      DIM Press(14)
10     DIM X(18,100),Sum(18),Mean(18),Sum2(18)
30     N=10
40     FOR I=1 TO N
50        OUTPUT 709;"AI1VT1"
60        ENTER 709:X(1,I)
70        OUTPUT 709;"AI2VT1"
80        ENTER 709:X(2,I)
90        OUTPUT 709:"AI3VT1"
100       ENTER 709:X(3,I)
110       OUTPUT 709;"AI4VT1"
120       ENTER 709:X(4,I)
130       OUTPUT 709;"AI5VT1"
140       ENTER 709:X(5,I)
150       OUTPUT 709;"AI6VT1"
160       ENTER 709:X(6,I)
170       OUTPUT 709;"AI7VT1"
180       ENTER 709:X(7,I)
190       OUTPUT 709;"AI8VT1"
200       ENTER 709:X(8,I)
210       OUTPUT 709;"AI9VT1"
220       ENTER 709:X(9,I)
230       OUTPUT 709:"AI10VT1"
240       ENTER 709:X(10,I)
250       OUTPUT 709;"AI11VT1"
260       ENTER 709:X(11,I)
261       OUTPUT 709;"AI12VT1"
262       ENTER 709:X(12,I)
263       OUTPUT 709;"AI13VT1)"
264       ENTER 709:X(13,I)
265       OUTPUT 709:"AI14VT1)"
266       ENTER 709:X(14,I)
267       OUTPUT 709:"AI15VT1)"
268       ENTER 709;X(15,I)
270    NEXT I
440    FOR J=1 TO 16
450       Sum(J)=0
460       FOR I=1 TO N
470          Sum(J)=Sum(J)+X(J,I)
480       NEXT I
490       Mean(J)=Sum(J)/N
510    NEXT J
```

```
520   FOR I=1 TO 14
530   READ A(I),B(I),C(I),D(I),Dist(I)
540   DATA -6.049177,3.92598,-.17336131,.0112105..5
550   DATA -7.059265,4.233834,-.2292065,.01415403,1.5
560   DATA -6.4905288,3.93412037,-.160249802,.009448598,2.5
570   DATA -7.05653853,4.69207328,-.341175732,.0189756532,3.5
580   DATA -7.00950749,4.15163753,-.207173977,.0123697788,4.5
590   DATA -6.38855694,3.93348997,-.160546739,.0095126941,5.5
600   DATA -6.58938462,3.95696947,-.164270383,.0096133938,6.5
610   DATA -6.587731,3.90750953,-.158062598,.0094269372,7.5
620   DATA -6.59491204,3.94889685,-.162699726,.009565139,8.5
630   DATA -6.35328646,3.92659595,-.165085722,.0099773509,9.5
640   DATA -6.20324295,3.84628939,-.146968664,.0088046866,10.5
650   DATA -20.2065629,11.1571691,-.0859126,.004917379,0
660   DATA -20.6682414,11.0677155,-.07562378,.011185984,0
670   DATA -18.8267355,11.9281137,-.17715903,.011005888,0
680   Press(I)=A(I)+B(I)*Mean(I)+C(I)*Mean(I)^2+D(I)*Mean(I)^3
681   Press(I)=Press(I)+14.696
690   NEXT I
```

```
700   Fb=1/453.6*(-234.396482+48715.7753*Mean(15)-11261.538*Mean(15)^2+33899.3*M
ean(15)^3)
710   Mwater=-.0063268+.002097278*Rr-.00000658*Rr^2+.000000011*Rr^3
720   Fn=Fb*22.5/22.0
730   Dw=.920/12
740   Dd=3/12
750   E=1/(1-Dw/Dd)
760   Dp=Mean(14)-Mean(13)
770   Cc=.62
771   K=Cc*E
772   Aa=3.1416*Dw^2/4
774   Y=1-(.41+.35*(Dw/Dd)^4*(Dp/(1.4*Mean(14))))
780   Gc=32.2
790   Den=.076297*Mean(12)/14.696
800   Mair=K*Aa*Y*SQR(2*Gc*Den*Dp*144)
810   Mtotal=Mair+Mwater
820   Vexit=Fn/(Mtotal)*32.2
830   PRINT
840   PRINT "PRESSURE AS A FUNCTION OF DISTANCE"
850   PRINT "___________________________________________"
860   PRINT "DISTANCE(X)","PRESSURE"
870   PRINT "____________________________"
880   FOR I=1 TO 14
890   PRINT Dist(I),Press(I)
900   NEXT I
910   PRINT "MASS FLOW RATE OF WATER =";Mwater;"LBM/SEC"
920   PRINT "MASS FLOW RATE OF AIR   =";Mair;"LBM/SEC"
930   PRINT "TOTAL MASS FLOW RATE    =";Mtotal;"LBM/SEC"
940   PRINT "THRUST                  =";Fn;"LBF"
950   PRINT "MIXTURE RATIO           =";Mwater/Mair
960   PRINT "EXIT VELOCITY           =";Vexit;"FT/SEC"
970   PRINT "INLET PRESSURE          =";Press(12);"PSI"
980   END
```

INPUT ROTOMETER READING
0

PRESSURE AS A FUNCTION OF DISTANCE

DISTANCE(X)	PRESSURE
.5	14.5598137417
1.5	14.4607948757
2.5	14.4788575371
3.5	14.4188520649
4.5	14.4711792506
5.5	14.5553698274
6.5	14.4532490549
7.5	14.4461409662
8.5	14.5336111051
9.5	14.5262956477
10.5	14.5245848183
0	14.1098474897
0	11.8981971096
0	17.6235437008

```
MASS FLOW RATE OF WATER =-.0063268 LBM/SEC
MASS FLOW RATE OF AIR   = .0110711550501 LBM/SEC
TOTAL MASS FLOW RATE    = .00474435505015 LBM/SEC
THRUST                  = 1.76920486692 LBF
MIXTURE RATIO           =-.571467021403
EXIT VELOCITY           = 12007.6166544 FT/SEC
INLET PRESSURE          = 14.1098474897 PSI
```

APPENDIX M: DUAL-PHASE TWO-COMPONENT COMPUTER PROGRAM

```
$JOB
C*****************************************************************
C      REAL TWO-PHASE TWO-COMPONENT NOZZLE FLOW                  *        MAIN0030
C      MODIFIED FOR USE AT NAVAL POSTGRADUATE SCHOOL              *        MAIN0150
C      PROF. J.SLADKY AND  LT. T.C.NOLLIE                         *        MAIN0190
C*****************************************************************
       COMMON TZZZAY                                                       MAIN0170
       DIMENSION TZZZAY(11200)                                             MAIN0210
C      THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP              MAIN0220
C      IT MUST BE THE FIRST COMMON BLOCK                                   MAIN0230
       COMMON    A      , ABAR   , ALAM   , ALPHAB , ALPHA  , ALPHMB ,     MAIN0240
     1           ALPHS  , AM     , AP     , AS     , AT     , BA     ,     MAIN0250
     2           BB     , BETAB  , BETAMB , BETA   , BETAS  , BM     ,     MAIN0260
     3           C      , C1     , CAG1   , CAGMB  , CAG    , CALMB  ,     MAIN0270
     4 CBG1    , CAL    , CASE   , CBGMB  , CBG    , CBLMB  , CBL          MAIN0280
       COMMON  ' CDMS   , CDP    , CD     , CFIM   , CFIMS  , CFOM   ,     MAIN0290
     6           CFOMS  , CGMB   , CGM    , CGMS   , CLMB   , CLM    ,     MAIN0300
     7           CLMS   , CSAVE  , D      , D2     , DA     , DATE   ,     MAIN0310
     8           DD     , DELIM  , DELI   , DELIS  , DELOM  , DELO   ,     MAIN0320
     9           DELOS  , DELSI  , DELSO  , DELTM  , DELT   , DELV2        MAIN0330
       COMMON    DEMAGB , DEMAG  , DEMBGB , DEMBG  , DEMGB  , DINT   ,     MAIN0340
     1           DLGIS  , DLSOS  , DO     , DP1    , DP     , DRAY   ,     MAIN0350
     2           DPI    , DRO    , DR     , DS1    , DSAVE  , DSLIM  ,     MAIN0360
     3           DSMAX  , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,     MAIN0370
     4           DSRPS  , DS     , DSX1   , DSY2   , DTG1   , DTGB         MAIN0380
       COMMON    DTG    , DTHI   , DTHO   , DTL1   , DTLB   , DTL    ,     MAIN0390
     6           DT     , DVBSQ  , DVGSQ  , DVLSQ  , DX     , DXL    ,     MAIN0400
     7           DYO    , EB     , EDS    , EMAGB  , EMAG   , EMBGB  ,     MAIN0410
     8           EMBG   , EMGB   , EMG    , EMGS   , EMLB   , EMLM   ,     MAIN0420
     9           EML    , EMLS   , EMT    , ESO    , FLEEP  , FUX          MAIN0430
       COMMON    H      , HJI    , HKAG   , HKBG   , HKGM1  , HKGM2  ,     MAIN0440
     1           HKGM   , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   ,     MAIN0450
     2           HLB1   , HLBM   , HLB    , HLBS   , HM     , HMS    ,     MAIN0460
     3           HOPE   , HT     , IACV   , IBLW   , IBLX   , IBW    ,     MAIN0470
     4           IJH    , INT    , ISET   , IZERO  , K      , K1           MAIN0480
       COMMON    K2     , KA2    , KDSCT  , KDS    , KL     , KR1    ,     MAIN0490
     6           KR     , KTBCT  , KTB    , KXP1   , KXP    , L      ,     MAIN0500
     7           L1     , L2     , LCT1   , LCT2   , LL     , LPSCT  ,     MAIN0510
     8           LSW    , MBU    , MFPO   , MFP    , MGEO   , MM     ,     MAIN0520
     9 M       , MOP    , MTHT   , NACV   , NB     , NCLK   , NCTS         MAIN0530
       COMMON  ' NDIAG  , NDS    , NGS    , NIB    , NIS    , NLST   ,     MAIN0540
     1           NNA    , NNB    , NNDS   , NNN    , NNP    , NN     ,     MAIN0550
     2           NNSOO  , NNSO   , NNS    , NP     , NSO    , NS     ,     MAIN0560
     3           P      , P10    , P11    , PAB    , PAMB   , PA     ,     MAIN0570
     4           PAS    , PBB    , PBMB   , PBOB   , PBO    , PB           MAIN0580
       COMMON    PBS    , PHIAB  , PHIBA  , PHI    , PINT   , PL     ,     MAIN0590
     6           PL1    , PO     , PS     , PT     , Q      , QID    ,     MAIN0600
     7           R1     , RA     , RAC    , RAXO   , RAX    , RB     ,     MAIN0610
     8           RC     , RDELIM , RDFIOM , RDIMS  , RDOMS  , REF    ,     MAIN0620
     9           REM    , REMS   , RESLIM , RESO   , RESZ   , RHOGB        MAIN0630
       COMMON    RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,     MAIN0640
     1           RIM    , RI     , RM     , ROALB  , ROAL   , ROBLB  ,     MAIN0650
     2           ROBL   , ROM    , RO     , R      , RSLIM  , RS     ,     MAIN0660
     3           RVB    , RV     , RVS    , S      , S1     , S2     ,     MAIN0670
     4           S3     , S4     , SA     , SB     , SGN    , SIG          MAIN0680
       COMMON    SIGS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,     MAIN0690
     6           SMLE   , SMLF   , SMLG   , SM     , SOJ1   , SOJ2   ,     MAIN0700
     7           SOP    , SO     , SOSM   , SS     , SZM    , SZO    ,     MAIN0710
     8           T      , TB     , TBRAY  , TBRAY1 , TGM3   , TGO    ,     MAIN0720
     9           TG     , TGS    , THIM   , THIO   , THT    , THIS         MAIN0730
       COMMON    THOM   , THOO   , THO    , THOS   , TK     , TKP    ,     MAIN0740
     1           TLMB   , TLO    , TL     , TLS    , TST    , TWIM   ,     MAIN0750
     2           TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAB    ,     MAIN0760
     3           VBD    , VBDS   , VBM    , VBMSQ  , V3     , VBSQ   ,     MAIN0770
     4           VBS    , VGO    , VG     , VGSQ   , VGS    , VIAG         MAIN0780
       COMMON    VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,     MAIN0790
     6           VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,     MAIN0800
     7           VL     , VLSO   , VLS    , VS     , VSS    , WAGB   ,     MAIN0810
     8           WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,     MAIN0820
     9           WBL    , WGB    , WG     , WGS    , WIM    , WIMS         MAIN0830
       COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLK   ,     MAIN0840
     1           XINT   , XP     , XS     , XX     , XXA    , Y1     ,     MAIN0850
```

```
     2          YIS       , YO       , YOS      , ZZZ      , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),OID(8),KP(2,75),PL1(10),
     1      C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TDRAY(100),TDRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      XX=-1.0
      SMIN = 1.0E-6
      IZERO = 0
      ISET = 75
      DINT(1)=.5
      DINT(2)=.1
      DINT(3)=.01
      DINT(4)=.001
      DINT(5)=.0001
      DINT(6)=.00001
      DINT(7)=.000001
      DINT(8)=.0000001
      CALL ADATA
C
C INITIALIZE TABLE TAPE, BRING IN PERMANENT TABLES (ONE-DIMENSIONAL),
C    FILL ARRAY INDICATING TEMPERATURES INCLUDED IN TWO
C    DIMENSIONAL TABLES, INITIALIZE PAGE COUNT.
C
    5 LPGCT=1
      CALL TABLE
      CALL INTEP(VAR,0,T,P)
C     ACTIVATE THE FOLLOWING CARD TO GET A PRINTOUT OF THE PROPERTIES
C     CALL INTEP(VAR,20,T,P)
      NSTMT=1999
  100 CONTINUE
      CALL SECT1
      IF(NSTMT-5)999,5,101
  101 CONTINUE
      IF(NSTMT-99) 999,99,200
  999 CALL DUMP
  200 CONTINUE
      CALL SECT2
      IF(NSTMT-40) 999,300,201
  201 IF(NSTMT-50) 999,300,202
  202 IF(NSTMT-60) 999,400,203
  203 IF(NSTMT-110) 999,700,999
  300 CONTINUE
      CALL SECT3
      IF(NSTMT-30) 999,200,301
  301 IF(NSTMT-70) 999,500,302
  302 IF(NSTMT-110) 999,700,303
  303 IF(NSTMT-145) 999,200,304
  304 IF(NSTMT-161) 999,200,305
  305 IF(NSTMT-1142) 999,200,999
  400 CONTINUE
      CALL SECT4
      IF(NSTMT-10) 999,200,401
  401 IF(NSTMT-110) 999,700,402
  402 IF(NSTMT-140) 999,600,403
  403 IF(NSTMT-161) 999,200,999
  500 CONTINUE
      CALL SECT5
      IF(NSTMT-30) 999,200,501
  501 IF(NSTMT-110) 999,700,502
  502 IF(NSTMT-2399) 999,600,999
  600 CONTINUE
      CALL SECT6
      IF(NSTMT-100) 999,500,601
  601 IF(NSTMT-110) 999,700,6020
 6020 IF(NSTMT-529) 999,800,602
  602 IF(NSTMT-1490) 999,500,999
  700 CONTINUE
      CALL THROAT
      IF(NSTMT-497) 999,800,999
  800 CONTINUE
```

```
      CALL DIAGNO
      IF(NSTMT-10) 999,100,801
  801 IF(NSTMT-63) 999,400,999
C
C   LAST CASE JUST COMPLETED.   PRINT OUT ALL INPUT TABLES
C     AND TERMINATE PROCESSING.
   99 T=LPGCT
      CALL INTRP(VAR,20,T,P)
      WRITE (6,9001)
      STOP
 9001 FORMAT(1H1 ,14HMAIN STATION 1    )
      END
                        SUBROUTINE SECT1
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A      , ABAR    , ALAM    , ALPHAB , ALPHA   , ALPHMB ,
     1          ALPHS  , AM      , AP      , AS     , AT      , BA     ,
     2          BB     , BETAB   , BETAMB  , BETA   , BETAS   , BM     ,
     3          C      , C1      , CAG1    , CAGMB  , CAG     , CALMB  ,
     4 CBG1   , CAL    , CASE    , CBGMB   , CBG    , CBLMB   , CSL
      COMMON    CDMS   , CDP     , CD      , CFIM   , CFIMS   , CFOM   ,
     6          CFOMS  , CGMB    , CGM     , CGMS   , CLMB    , CLM    ,
     7          CLMS   , CSAVE   , D       , D2     , DA      , DATE   ,
     8          DD     , DELIM   , DELI    , DELIS  , DELOM   , DELO   ,
     9          DELOS  , DELSI   , DELSO   , DELTM  , DELT    , DELV2
      COMMON    DEMAGB , DEMAG   , DEMBGB  , DEMBG  , DEMGB   , DINT   ,
     1          DLSIS  , DLSOS   , DO      , DP1    , D2      , DRAY   ,
     2          DRI    , DRO     , DR      , DS1    , DSAVE   , DSLIM  ,
     3          DSMAX  , DSMIN   , DSRAY1  , DSRAY  , DSRES1  , DSRES2 ,
     4          DSRES  , DS      , DSX1    , DSX2   , DTG1    , DTGB
      COMMON    DTG    , DTHI    , DTHO    , DTL1   , DTLB    , DTL    ,
     6          DT     , DVBSQ   , DVGSQ   , DVLSQ  , DX      , DYI    ,
     7          DYD    , EB      , EDS     , EMAGB  , EMAG    , EMBGB  ,
     8          EMBG   , EMGB    , EMG     , EMGS   , EMLB    , EMLM   ,
     9          EML    , EMLS    , EMT     , F30    , FLERP   , FUX
      COMMON    H      , HJI     , HKAG    , HKGG   , HKGM1   , HKGM2  ,
     1          HKGM   , HKGMS   , HLA1    , HLAM   , HLA     , HLAS   ,
     2          HLB1   , HLBM    , HLB     , HLBS   , HM      , HMS    ,
     3          HOPE   , HT      , IACV    , IBLW   , IBLK    , IJW    ,
     4          IJH    , INT     , ISET    , IZERO  , K       , K1
      COMMON    K2     , KAP     , KDSCT   , KDS    , KL      , KR1    ,
     6          KR     , KTBCT   , KTB     , KXP1   , KXP     , L      ,
     7          L1     , L2      , LCT1    , LCT2   , LL      , LPGCT  ,
     8          LSW    , MAG     , MFPO    , MFP    , MGPO    , MM     ,
     9 N      , MOP    , MTHT    , NACV    , NB     , NCLK    , NCPS
      COMMON    NDIAG  , NDS     , NGG     , NTB    , NTS     , NLST   ,
     1          NNA    , NNB     , NNDS    , NNN    , NPP     , NN     ,
     2          NNSOO  , NNSO    , NNS     , NP     , NSO     , NS     ,
     3          P      , P10     , P11     , PAB    , PAMB    , PA     ,
     4          PAS    , PBB     , PBMB    , PBOB   , PBO     , PB
      COMMON    PBS    , PHIAB   , PHIBA   , PHI    , PINT    , PL     ,
     6          PL1    , PO      , PS      , PT     , Q       , QID    ,
     7          R1     , RA      , RAS     , RAXO   , RAX     , RB     ,
     8          RC     , RDELIM  , RDELOM  , RDIMS  , RDOMS   , REF    ,
     9          REM    , REMS    , RESLIM  , RESO   , RESZ    , RHOG3
      COMMON    RHOG   , RHOGS   , RHOLB   , RHOLM  , RHOL    , RHOLS  ,
     1          RIM    , RI      , RM      , ROALB  , ROAL    , ROBLB  ,
     2          ROBL   , ROM     , RO      , R      , RSLIM   , RS     ,
     3          RVB    , RV      , RVS     , S      , S1      , S2     ,
     4          S3     , S4      , SA      , SB     , SGN     , SIG
      COMMON    SIGS   , SMIN    , SMJ1    , SMJ2   , SMLC    , SMLD   ,
     6          SMLE   , SMLF    , SMLG    , SM     , SOJ1    , SOJ2   ,
     7          SOP    , SO      , SOSM    , SS     , SUM     , SZD    ,
     8          T      , TB      , TBRAY   , TBRAY1 , TGMB    , TGO    ,
     9          TG     , TGS     , THIM    , THIO   , THI     , THIS
      COMMON    THOM   , THOO    , THO     , THOS   , TK      , TKT    ,
     1          TLM3   , TLO     , TL      , TLS    , TST     , TWIM   ,
     2          TWIMS  , TWOM    , TWOMS   , V1     , V2      , VAR    ,
     3          VBD    , VBDS    , VBM     , VBMSQ  , VB      , VBSQ   ,
     4          VBS    , VGO     , VG      , VGSQ   , VGS     , VIAG
```

```
      COMMON    VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,
     6          VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,
     7          VL    ., VLSQ   , VLS    , VS     , VSS    , WASB   ,
     8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,
     9          WBL    , WGB    , WG     , WGS    , WIM    , WIMS
      COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLK   ,
     1          XINT   , XP     , XS     , XX     , XXA    , YI     ,
     2          YIS    , YO     , YOS    , ZZZ    , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1       C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
C     ************************************************************************
C     **************** STATEMENT NO. 10  **************************************
C     ************************************************************************
   10 CONTINUE
      NSTMT=9999
C     DO WE HAVE TO WOT  (XX=-1.0 IN MAIN)  SET (POSSIBLY) IN SECT4
      IF(XX+1.0)1,2,1
    1 CONTINUE
      WRITE (6,8077) XX
      XX=-1.0
    2 CONTINUE
C READ INPUTS AND PRINT HEADING FOR THIS CASE
      READ (5,910,END=7777) (DATE(I),I=1,5),(CASE(I),I=1,3),(QID(I),
     1I=1,8),NS,NP
      IF(NS)5,99,11
   99 NSTMT=99
      RETURN
   11 CONTINUE
      READ (5,911) MBU,MOP,MGEO,NDS,NSO,NB,NNS
      READ (5,912) DP,EC,PHI,RAXO,EMT,H,ALAM,DP1,
     1WAL,WBL,SA,SB,DO,PO,TGO,TLO,VGO,VLO,THOO,THIO,EDS,ESO,
     2EB
      WRITE (6,913) DATE,CASE,QID,NS,NP,
     1MBU,MOP,    MGEO,NDS,NSO,NB,    NNS,DP,EC,PHI,RAXO,EMT,
     2H,ALAM,WAL,WBL,SA,SB,DO,PO,TGO,TLO
      WRITE (6,9913) VGO,VLO,THOO,THIO,EDS,ESO,EB,DP1
      NDIAG=0
      NNN=0
      KAP=1
      NACV = 0
      MM=0
      IACV = 0
      KTB = 1
      KDS = 1
       LCT2=0
      K1=1
      K2=1
      KDSCT=0
      KIDCT=0
      NCTS=0
      LCT1=30
      K=1
C
C  GET X(P) TABLE IDENTIFICATION AND X(P) TABLE DATA POINTS.
C
      IF(MOP)1360,14,1360
   14 READ (5,9914) (XXA(I),I=1,8)
      WRITE (6,9915) (XXA(I),I=1,8)
C
C READ IN X(P) TABLE IF MOP=0
      DO 8000 KP=1,75
      DO 8000 JP=1,2
      XP(JP,KP)=-1.0
 8000 CONTINUE
C
    9 READ (5,914) (C(L),L=1,6)
      DO 1320 L=1,5,2
      IF(C(L)-C(L+1))18,15,18
```

```
   15 IF(C(L)- 100000.) 18,9916,18
   18 XP(1,K)=C(L)
      XP(2,K)=C(L+1)
      IF(K-ISET) 19,19,21
   19 K=K+1
 1320 CONTINUE
      GO TO 3
 9916 K = K-1
C        THIS IS A FIX FOR PRESSURE TABLE INTERP AT STEP 51    JHH
      KXP1 = K
C
C PRINTOUT X(P) TABLE JUST READ IN
C
      L1=1
      L2=8
      WRITE (6,915)
   16 WRITE (6,909)  (XP(1,LT),LT=L1,L2)
      WRITE (6,917)  (XP(2,LT),LT=L1,L2)
      LCT1=LCT1+3
      IF(L2-K) 13,22,22
   13 L1=L1+8
      L2=AMIN0(L2+8,K)
      IF(LCT1-52)16,17,17
C
C MAXIMUM LINE COUNT EXCEEDED - START NEW PAGE.
C
   17 WRITE (6,918) LPGCT
      LCT1=4
      LPGCT=LPGCT+1
      GO TO 16
C
C X(P) TABLE LIMITS EXCEEDED - PRINT ERROR MESSAGE AND
C    EXIT TO NEXT CASE.
C
   21 WRITE (6,921)
      GO TO 10
C
   22 CONTINUE
C
C APPROPRIATE TABLES HAVE BEEN READ IN AS REQUIRED
C
 1360 CONTINUE
      WRITE (6,916)
      RETURN
    5 NSTMT=5
      RETURN
 7777 STOP
  909 FORMAT(1H0,3X,5HPRESS,1X,1P8E15.4)
  910 FORMAT(4A4,A2,3A4,7A4,A2,2I6)
  911 FORMAT(11I6)
  912 FORMAT(5F12.6,/,5F12.6,/,6E12.6,/,5E12.6)
  913 FORMAT(1H1 ,  7X, 4HREAL T.)-,
     131HPHASE TWO-COMPONENT NOZZLE FLOW ,/
     2                       ,9X,4A4,A2,/,9X,12HCASE NUMBER ,3A4,/,
     38X,7A4,A2,/// ,10X,2HS, 10X,2HP,9X,3HRBU,9X,3HROP,
     48X,4HMGEO,9X,3HRDS,9X,3HRSO, 10X,2HIB,           9X,3HRNS,/,
     5 9(6X,I6),//,20X,2HDT,13X,2HFC,12X,3HPHI,11X,4HMAXO,
     612X,3HENT,              14X,1HH,11X,4HALAM,/,11X,7F15.4,
     7//,10X,3HVAL,12X,3HWEL,13X,2HSA,13X,2HSB,13X,2HDO,13X,
     82HEO,12X,3HTGO,12X,3HTLO,/,11X,1P8E15.4,//,19X,3HVGO,12X,
     93HVLO,11X,4ITHGO,11X,4HTHLO,12X,3HEDS,12X,3HESO,13X,2HED)
  914 FORMAT(6E12.6)
  915 FORMAT(1H0,58X,16HX(P) TABLE INPUT)
  916 FORMAT(1H0,7X,23HPRINTOUT-STATION OUTPUT  )
  917 FORMAT(1H ,7X,1HX,1X,1P8E15.4)
  918 FORMAT(1H1 ,120X,5HPAGE ,I3,///,55X,18HX(P) TABLE (CONT.))
  921 FORMAT(1H0,29HX(P) TABLE LIMITS EXCEEDED - ,
     118HREAD IN NEXT CASE.)
 9913 FORMAT(1H0,10X,1P7E15.4//19X,3HDP1,
     1/,11X,E15.4)
 9914 FORMAT(7A4,A2)
 9915 FORMAT(1H0,19HX(P) TABLE FOLLOWS ,15X,11HTABLE ID - ,
```

```
      1        7A4,A2)                                                          SEC12120
 8077 FORMAT(1H0,10X,19HISOTHERMAL FLOW TO ,1PE16.4 , 6H PSIA.  )               SEC12130
      END                                                                       SEC12140
                    SUBROUTINE SECT2                                            SEC20010
      COMMON TZZZAY                                                             SEC20020
      DIMENSION TZZZAY(11200)                                                   SEC20030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP                    SEC20050
C     IT MUST BE THE FIRST COMMON BLOCK                                         SEC20060
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB ,      SEC20070
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,     SEC20080
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,     SEC20090
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,     SEC20100
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL            SEC20110
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,     SEC20120
     6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,     SEC20130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,     SEC20140
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,     SEC20150
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2          SEC20160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT    ,     SEC20170
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,     SEC20180
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,     SEC20190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,     SEC20200
     4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB           SEC20210
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,     SEC20220
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI     ,     SEC20230
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMBGB   ,     SEC20240
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,     SEC20250
     9          EML     , EMLS    , EMT     , ETO     , FLSEP   , FHK            SEC20260
      COMMON    H       , HJI     , HKAG    , HKBG    , HKGM1   , HKGM2   ,     SEC20270
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,     SEC20280
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,     SEC20290
     3          HOPE    , IT      , IACV    , IBLW    , IBLX    , IBW     ~     SEC20300
     4          IJH     , INT     , ISET    , IZERO   , K       , K1             SEC20310
      COMMON    K2      , KAP     , KDECT   , KDS     , KL      , KR1     ,     SEC20320
     6          KR      , KTBCT   , KTB     , KXP1    , KXP     , L       ,     SEC20330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT   ,     SEC20340
     8          LSW     , MBU     , MFDO    , MFP     , MGZO    , MM      ,     SEC20350
     9 TN     , MOP     , MTPT    , NACV    , NB      , NCLK    , NCT5           SEC20360
      COMMON    NDIAG   , NDS     , NGS     , NTB     , NIS     , NLST    ,     SEC20370
     1          NNA     , NNB     , NNDS    , NNN     , NNP     , NN      ,     SEC20380
     2          NNSGO   , NNSO    , NNS     , NP      , NSO     , NS      ,     SEC20390
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,     SEC20400
     4          PAS     , PBB     , PBMB    , PROB    , PBO     , PB             SEC20410
      COMMON    PBS     , PHTAB   , PHIBA   , PHI     , PINT    , PL      ,     SEC20420
     6          PL1     , PO      , PS      , PT      , Q       , QIO     ,     SEC20430
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,     SEC20440
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , REF     ,     SEC20450
     9          REM     , REMS    , RESLIM  , RESO    , RESE    , RHOGB          SEC20460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,     SEC20470
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,     SEC20480
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,     SEC20490
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,     SEC20500
     4          S3      , S4      , SA      , SB      , SCN     , SEI            SEC20510
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,     SEC20520
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,     SEC20530
     7          SOP     , SO      , SOSM    , SS      , SZM     , SZO     ,     SEC20540
     8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO     ,     SEC20550
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS           SEC20560
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKT     ,     SEC20570
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,     SEC20580
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR     ,     SEC20590
     3          VBD     , VBDS    , VBM     , VBMSQ   , V3      , VBSQ    ,     SEC20600
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG           SEC20610
      COMMON    VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,     SEC20620
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,     SEC20630
     7          VL      , VLSQ    , VLS     , VS      , VSS     , WAGB    ,     SEC20640
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,     SEC20650
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS           SEC20660
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,     SEC20670
     1          XINT    , XP      , XS      , XX      , XXA     , XI      ,     SEC20680
     2          XIS     , XO      , XOS     , ZZZ     , NSTMT                    SEC20690
      DIMENSION PL(10)                                                          SEC20700
```

```
      DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1        C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TDRAY(100),TDRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-30) 1,30,2
    1 CALL DUMP
    2 IF(NSTMT-145) 1,145,3
    3 IF(NSTMT-161) 1,161,4
    4 IF(NSTMT-1142) 1,1142,5
    5 CONTINUE
C
C  SET ITERATION COUNT ZERO
C
      NNA=0
C
C  SET INITIAL CONDITIONS INDICATION
C
C     *************** STATEMENT NO. 20  ********************************
C     ****************************************************************
   20 MEP=1
      MEPO=1
      IBLX=0
      KAP=1
      NNN=0
      BO=0.0
      PHI=PHI*0.01745329
      AT=100000.0
C
C INITIALIZE PRINTOUT COUNT
C
      NNP=1
C
C SETUP MIDPOINT AND ENDPOINT INDICATION.
C    INT = 1, NEXT ENTRY TO STATEMENT 32 COMPUTES MIDPOINT
C     QUANTITIES.
C    INT = 0, NEXT ENTRY TO STATEMENT 32 COMPUTES ENDPOINT
C     QUANTITIES.
C
      INT=1
C
C  RESET THROAT INDICATOR
C    MTHT = 0 - THROAT NOT REACHED
C    MTHT = 1 - THROAT REACHED
C
      MTHT=0
C
C  RESET DS ITERATION COUNTER.
C
      NNDS=0
C  RESET OPTIMUM S ITERATION COUNTER.
C
C
      NNSO=0
C
C  BACKSTEP P FOR FIRST ENTRY TO 30
C
      P= PO-DP1/2.0
C
C  SETUP INITIAL CONDITIONS
C
      TG=TGO
      TL=TLO
      VG=VGO
      VL=VLO
      D=DO
   28 X=0.
   27 DTL=0.0
      DS1=0.
      B=0.
      DTG=0.0
      AT=0.
```

```
      VGSQ=VG*VG
      VLSQ=VL*VL
      THO=THOO
      THI=THIO
      DELT=TG-TL
      DELV2=VGSQ-VLSQ
      DS1=0.
      R=0.
      DTHO=0.0
      DTHI=0.0
C
C     *************** STATEMENT NO. 30  **********************************
C     ************************************************************************
   30 NSTMT=9999
      IF(NPP) 631,630,630
C
C  THIS IS FIRST POINT - HALF STEP P BY INITIAL DP STEP-SIZE.
C
  631 P=P+DP1/2.0
      GO TO 632
C
C  THIS IS NOT FIRST POINT - HALF STEP PRESSURE BY STEP
C     SIZE DP.
C
  630 P=P+DP/2.0
  632 IF(P) 1130,1130,131
C
C  STEPPING PRESSURE MADE IT NEGATIVE - PRINT DIAGNOSTIC, AND
C   DATA COMPUTED TO THIS POINT AND GO TO NEXT CASE.
C
 1130 WRITE (6,930)
      LL=1
      GO TO 500
C
C  EXTRAPOLATE TG AND TL, PRINT DIAGNOSTICS IF THEY GO
C     NEGATIVE, AND PRINT DATA COMPUTED TO THIS POINT.
C
  131 CONTINUE
      TG=TG+DTG/2.0
      IF(TG) 132,132,133
  132 WRITE (6,931)
      LL=2
      GO TO 500
  133 TL=TL+DTL/2.0
      IF(TL) 134,134,135
  134 WRITE (6,932)
      LL=3
      GO TO 500
C
C  INTERPOLATE FOR PBO FOR THIS TL
C
  135 N=9
      NN=9
      CALL INTEP(PBO,N,TL,P)
      IF(N) 136,136,137
  136 WRITE (6,9136) HT(NN),TL,P
      LL=3
      GO TO 500
C
C  CHECK DENOMINATOR OF EQUATION FOR PARTIAL PRESSURE
C     OF COMPONENT A, PRINT DIAGNOSTIC IF SUFFICIENTLY
C     CLOSE TO ZERO RENDERING PA INFINITE.
C
  137 IF(ABS(1.0-H*PBO)-.0001) 138,138,139
  138 WRITE (6,938)
      LL=3
      GO TO 500
  139 PA=(P-PBO)/(1.0-H*PBO)
C
C  COMPUTE PA AND PB. IF EITHER IS NEGATIVE, PRINT
C     DIAGNOSTIC AND GO TO NEXT CASE.
C
```

```
      IF(PA) 439,440,440
  439 WRITE (6,9439)
      LL=4
      GO TO 500
  440 PB=P-PA
      IF(PB) 441,442,442
  441 WRITE (6,9440)
      LL=5
      GO TO 500
C
C  INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT A
C    GAS TABLE AT TEMPERATURE TG.
C
  442 N=3
      NN=3
      CALL INTRP(WAG,N,TG,PA)
      IF(N) 1141,1141,143
 1141 LL=5
 1142 WRITE (6,9136) HT(NN),TG,PA
      NSTMT=9999
      GO TO 500
C
C  INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT B
C    GAS TABLE AT TEMPERATURE TG.
C
  143 N=4
      NN=4
      CALL INTRP(WBG,N,TG,PB)
      IF(N) 144,144,150
  144 LL=6
  145 WRITE (6,9136) HT(NN),TG,PB
      NSTMT=9999
      GO TO 500
C
C  COMPUTE MEAN MOLECULAR WEIGHT OF GAS MIXTURE.
C
  150 WG=(WAG*PA+WBG*PB)/P
C
C  COMPUTE RATIO OF FLOW RATE OF LIQUID A TO FLOW
C    RATE OF LIQUID MIXTURE OF A AND B - ALPHA
C
      ALPHA=((WAL/WBL)*H*PA)/(1.0+((WAL/WBL)-1.0)*H*PA)
C
C  COMPUTE RATIO OF FLOW RATE OF GAS B TO FLOW RATE
C    OF GAS MIXTURE OF A AND B - BETA
C
      BETA=(WBG*PB)/(WG*P)
C
C  COMPUTE RATIO OF FLOW RATE OF LIQUID MIXTURE TO
C    FLOW RATE OF GAS MIXTURE, R. CHECK DENOMINATOR OF
C    EQUATION FOR R AND PRINT DIAGNOSTIC IF SUFFICIENTLY
C    CLOSE TO ZERO.
C
      IF(ABS(1.0-(1.0+RC)*ALPHA)-.0001) 151,152,152
  151 WRITE (6,9151)
      LL=7
      GO TO 500
  152 DR=((RC-(1.+RC)*BETA)/(1.0-(1.0+RC)*ALPHA))-R
      R=R+DR
C
C  COMPUTE GAS DENSITY - RHOG
C
      RHOG=(WG*P)/(TG*10.732)
C
C  INTERPOLATE IN TABLE FOR DENSITY OF LIQUID A AT THIS
C    TEMPERATURE.
C
      N=10
      NN=10
      CALL INTRP(ROAL,N,TL,P)
      IF(N) 160,160,162
C
```

```
C
C  TABLE LIMITS EXCEEDED - WRITE DIAGNOSTIC.
C
  160 LL=8
  161 WRITE (6,9136) HT(NN),TL,P
      NSTMT=9999
      GO TO 500
C
C  INTERPOLATE IN TABLE FOR DENSITY OF LIQUID B AT THIS
C     TEMPERATURE.
  162 N=11
      NN=11
      CALL INTEP(ROBL,N,TL,P)
      IF(N) 161,161,163
C
C  COMPUTE DENSITY OF LIQUID MIXTURE
C
  163 RHOL=1.0/((ALPHA/ROAL)+((1.0-ALPHA)/ROBL))
C
C  COMPUTE FLOW RATES OF LIQUID MIXTURE AND OF GAS MIXTURE.
C
      EMG=EMT/(1.0+R)
      EML=R*EMG
C
C  COMPUTE RATIO OF GAS VOLUME FLOW TO LIQUID VOLUME FLOW.
C
      RV=RHOL/(R*RHOG)
C
C  INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT
C     THIS TEMPERATURE AND PRESSURE.
C
      N=1
      NN=1
      CALL INTEP(CAG,N,TG,PA)
      IF(N) 165,165,170
  165 LL=9
      GO TO 1142
  170 N=2
      NN=2
      CALL INTEP(CBG,N,TG,PB)
      LL=9
      IF(N) 145,145,171
C  INTERPOLATE INTO LATENT HEAT OF VAPORIZATION TABLES
C     FOR A AND B AT THIS TEMPERATURE.
C
  171 N=7
      NN=7
      CALL INTEP(HLA,N,TL,P)
      LL=9
      IF(N) 161,161,172
  172 N=8
      NN=8
      CALL INTEP(HLB,N,TL,P)
      LL=10
      IF(N) 161,161,31
   31 IF(MFP-1) 32,40,32
   32 IF(ITT-1) 60,50,60
   40 NSTMT=40
      RETURN
   50 NSTMT=50
      RETURN
   60 NSTMT=60
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LPGCT,MGEO)
      NSTMT=110
      RETURN
  930 FORMAT(1H0,7X,13HNONPOSITIVE P)
  931 FORMAT(1H0,7X,14HNONPOSITIVE TG)
  932 FORMAT(1H0,7X,14HNONPOSITIVE TL)
  938 FORMAT(1H0,7X,11HINFINITE PA)
 9136 FORMAT(1H0,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,
```

```
     14HT = ,1PE12.4,5X,4HP =  ,E12.4)
9151 FORMAT(1H0,7X,10HINFINITE R)
9439 FORMAT(1H0,7X,11HNEGATIVE PA)
9440 FORMAT(1H0,7X,11HNEGATIVE PB)
     END
                SUBROUTINE SECT3
     COMMON TZZZAY
     DIMENSION TZZZAY(11200)
C    THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C    IT MUST BE THE FIRST COMMON BLOCK
     COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
    1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,
    2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
    3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
    4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL
     COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
    6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,
    7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,
    8          DD      , DELIM   , DELT    , DELIS   , DEIOM   , DELO    ,
    9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2
     COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT    ,
    1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,
    2          DRI     , DRO     , DR      , DS1     ,.DSAVE   , DSLIM   ,
    3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,
    4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB
     COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,
    6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI     ,
    7          DYO     , ED      , EDS     , EMAGB   , EMAG    , EMBGB   ,
    8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,
    9          EML     , EMLS    , EMT     , ESO     , FLEEP   , FUK
     COMMON    H       , HJI     , HKAG    , HKPG    , HKGM1   , HKGM2   ,
    1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,
    2          HLB1    , HLBM    , HLF     , HIJS    , H*      , HMS     ,
    3          HOPE    , HT      , IACV    , IBLW    , IBLX    , IB*     ,
    4          IJJ     , INT     , ISET    , IZERO   , K       , K1
     COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KR1     ,
    6          KR      , KTBCT   , KTB     , KXP1    , KXP     , L       ,
    7          L1      , L2      , LCT1    , LCT2    , LL      , LPSCT   ,
    8          LSW     , MBU     , MFPO    , MFP     , MGFO    , M1      ,
    9 N      , MOP     , MTHT    , NACV    , NB      , NCLX    , NCPS
     COMMON    NDIAG   , NDS     , NGG     , NIB     , NIS     , NLST    ,
    1          NNA     , NNB     , NNDS    , NNH     , NNP     , NN      ,
    2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,
    3          P       , P10     , P11     , PAB     , PAMB    , PA      ,
    4          PAS     , PB3     , PBMB    , PROB    , P30     , P3
     COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,
    6          PL1     , PO      , PS      , PT      , Q       , QID     ,
    7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,
    8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , REF     ,
    9          REM     , REMS    , RESLIM  , RESO    , RETZ    , RHOGB
     COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,
    1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,
    2          RCBL    , ROM     , RO      , R       , RSLIM   , RS      ,
    3          RV3     , RV      , RVS     , S       , S1      , S2      ,
    4          S3      , S4      , SA      , SB      , SGN     , SIG
     COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,
    6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,
    7          SOP     , SO      , SOSM    , SS      , SZ*     , SZO     ,
    8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO     ,
    9          TG      , TGS     , THIM    , THIO    , THI     , THIS
     COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKP     ,
    1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,
    2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAL     ,
    3          VBO     , VBOS    , VBM     , VBMSQ   , V3      , VBSQ    ,
    4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG
     COMMON    VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,
    6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,
    7          VL      , VLSQ    , VLS     , VS      , VSG     , WAGB    ,
    8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,
    9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS
     COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,
    1          XINT    , XP      , XS      , XX      , XXA     , YI      ,
```

```
      2          YIS     , YO      , YOS     , ZZZ     , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1     C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-40) 1,40,2
    1 CALL DUMP
    2 IF(NSTMT-50) 1,50,1
C
C  THIS IS FIRST POINT - STORE INITIAL PROPERTIES FOR USE
C    AT END OF FIRST INTERVAL.
C
C     **************** STATEMENT NO. 40  ********************************
C     *******************************************************************
   40 MPP=0
      NSTMT=9999
      HLA1=HLA
      HLB1=HLB
      CAG1=CAG
      CBG1=CBG
C
C  COMPUTE INITIAL FLOW RATES OF COMPONENTS A AND B.
C
      EMAG=(EMG*WAG*PA)/(WG*P)
      EMBG=(EMG*WBG*PB)/(WG*P)
      DR=0.0
      IF(VG) 175,175,174
  174 IF(VL) 175,175,176
  175 A=1000000.
      RA=A
      GO TO 41
C
C  COMPUTE INITIAL AREA OF NOZZLE.
C
  176 A=144.*EMG*((1.0/(RHOG*VG))+(R/(RHOL*VL)))
      RA=RV*VL/VG
   41 AT=A
      PT=P
      AP(1,1)=P
      AP(2,1)=A
      KAP=2
C
C  COMPUTE SLIP VELOCITY, VS, MEAN FREE STREAM VELOCITY, VB, AND
C    SLIP FRACTION, S.
C
   42 VS=VG-VL
      VB=(VG+R*VL)/(1.0+R)
      VBSQ= VB*VB
      S=VS/VB
      IF(MGEO) 180,179,180
C
C  NOZZLE IS CIRCULAR - COMPUTE DISTANCE FROM NOZZLE AXIS TO
C    WALL OF NOZZLE, YI.
C
  179 YO=SQRT(A/3.1416)
      YI=0.0
      RI=0.0
      GO TO 43
C
C  NOZZLE IS ANNULAR - COMPUTE RADII AND DISTANCES TO WALL
C    OF ANNULAR NOZZLE, RI,RO,YI,YO.
C
  180 TST=(RAXC**2)-((A*COS(PHI))/(2.0*3.1416))
      IF(TST) 181,182,182
  181 WRITE (6,9181)
      LL=11
      GO TO 500
  182 RI=SQRT(TST)
      RO=(RAXO**2)+((A*COS(PHI))/(2.0*3.1416))
      RO=SQRT(RO)
```

```
      YI=(RAXO-RI)/COS(PHI)
      YO=(RO-RAXO)/COS(PHI)
C
C WRITE LINES 1,2,3 OF OUTPUT AND GO TO 30.
C
   43 IF(LCT1-42)644,643,643
  643 LCT1=0
      WRITE (6,9643) LPGCT
      LPGCT=LPGCT+1
  644 WRITE (6,1001) X,P,R,VB,A,TG,TL,VG,VL
      WRITE (6,1002) VS,S,D,WV,RA,ALPHA,BETA,EMG,EML
      WRITE (6,1003) RHOG,RHOL,WAG,WBG,WG,PA,PB,HLA,HLB
      LCT1=LCT1+9
      GO TO 30
C
C  MIDPOINT OF INTERVAL - COMPUTE MID-POINT PARAMETERS.
C    RESET MIDPOINT/ENDPOINT INDICATOR SO NEXT ENTRY TO 32
C    WILL BE AN ENDPOINT.
C
C     **************** STATEMENT NO. 50  **********************************
C     ******************************************************************
   50 INT=0
      NSTMT=9999
C
C  INTERPOLATE IN VISCOSITY (GAS) TABLES FOR A AND B AT
C    THIS GAS TEMPERATURE.
C
      N=16
      NN=16
      CALL INTRP(VIAG,N,TG,PA)
      IF(N)205,205,206
  205 LL=12
      GO TO 1142
  206 N=17
      NN=17
      CALL INTRP(VIBG,N,TG,PB)
      IF(N)207,207,208
  207 LL=12
      GO TO 145
C
C  INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT
C    THIS LIQUIDS TEMPERATURE.
C
  208 N=5
      NN=5
      CALL INTRP(CAL,N,TL,P)
      LL=12
      IF(N)161,161,209
  209 NN=6
      N=6
      CALL INTRP(CBL,N,TL,P)
      LL=12
      IF(N)161,161,210
C
C  COMPUTE MEAN SPECIFIC HEATS OF LIQUID, CLM, AND OF
C    GAS, CGM.
C
  210 CLM=ALPHA*CAL+(1.0-ALPHA)*CBL
      CGM=(1.0-BETA)*CAG+BETA*CBG
      PHIAB=((1.0+((VIAG/VIBG)**.5)*((WBG/WAG)**.25))**2)/
     1      (2.828*((1.0+WAG/WBG)**.5))
      PHIBA=((1.0+((VIBG/VIAG)**.5)*((WAG/WBG)**.25))**2)/
     1      (2.828*((1.0+WBG/WAG)**.5))
C
C  COMPUTE MEAN VISCOSITY OF A AND B GAS.
C
      VIGM=(VIAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*PHIAB))+
     1      (VIBG/(1.0+(((1.0-BETA)/BETA)*(WBG/WAG)*PHIBA)))
C
C  INTERPOLATE IN VISCOSITY (LIQUID) TABLES FOR A AND B AT
C    THIS TEMPERATURE.
C
```

```
      N=14
      NN=14
      CALL INTRP(VIAL,N,TL,P)
      LL=13
      IF(N) 161,161,215
  215 N=15
      NN=15
      CALL INTRP(VIBL,N,TL,P)
      LL=13
      IF(N) 161,161,216
C
C COMPUTE MEAN THERMAL CONDUCTIVITY OF GAS MIXTURE, HKGM.
C     BA AND BE ARE USE SUBSEQUENTLY IN DETERMINING HKGM.
C
  216 VILM=ALPHA*VIAL+(1.0-ALPHA)*VIBL
      T1=(SQRT(SA*SB)/TG+1.0)*0.25
      T2=1.0+SA/TG
      T3=1.0+SB/TG
      T4=T2/T3
      T5=(WAG/WBG)**0.75
      T6=VIAG/VIBG
      T7=SQRT(T6*T4*T5)
      BA=T1/T2*(1.0+T7)**2
      BB=T1/T3*(1.0+1.0/T7)**2
C
C    INTERPOLATE IN THERMAL CONDUCTIVITY TABLES FOR COMPONENTS
C     A AND B IN GASEOUS STATE.
C
      N=12
      NN=12
      CALL INTRP(HKAG,N,TG,P)
      LL=13
      IF(N) 145,145,220
  220 N=13
      NN=13
      CALL INTRP(HKBG,N,TG,P)
      LL=13
      IF(N) 145,145,221
C
C     IF BETA=1, FIRST TERM OF HKGM IS SET=0
C     IF BETA=0, SECOND TERM OF HKGM IS SET=0
C
  221 IF(BETA-1.0) 223,222,223
  222 HKGM1=0.0
      GO TO 224
  223 HKGM1=HKAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*BA)
  224 IF(BETA) 226,225,226
  225 HKGM2=0.0
      GO TO 227
  226 HKGM2=HKBG/(1.0+((1.0+BETA)/BETA)*(WBG/WAG)*BB)
  227 HKGM=HKGM1+HKGM2
C
C     COMPUTE V1,V2,R1, HERE FOR USE IN ITERATIVE LOOP AT
C     STATEMENT NO. 70.
C
      V1=((99443.6*TG)/((1.0+R)*WG))*ALOG
     1      ((P+DP/2.0)/(P-DP/2.0))
      V2=(9266.08*V*DP)/((1.0+R)*RHOL)
      R1=(300.0*RHOG*D)/VIGM
      IF(MOP) 51,52,51
C
C   OPTIMUM X(F) IS TO BE USED.
C
C     *************** STATEMENT NO. 51  ***********************************
C     ********************************************************************
   51 C1=(D*ALAM*RHOL)/(9.0*RHOG)
      SMLG=R/((1.0+R)**2)
16070 KDS = 1
      KDSCT = 0
      NNSO = 0
      NNSOO = 0
      DSMIN = -2.*(S+(1.+R)/R)+1.0E-06
```

```
      DSMAX = 1.0 + R - 1.0E-06
      GO TO 70
C
C   SPECIFIED X(P) IS TO BE USED.
C
   52 P10=P+DP/2.0
      P11=P-DP/2.0
      PINT=P10
      KL=1
      GO TO 1100
 1152 X10=XINT
      PINT=P11
      KL=2
      GO TO 1100
 1153 X11=XINT
C
C   GET DIFFERENCE OF INTERPOLATED X VALUES FROM
C    X(P) TABLE
C
      DX=X10-X11
      S1=(0.75*RHOG*(1.0+R)*DX)/(D*RHOL)
      S2=(4633.04*(1.0+R)*DP)/RHOL
      S3=(1.0+R)/2.0
      S4=2.0*DR/(1.0+R)
      GO TO 16070
C
C   INTERPOLATE INTO X(P) TABLE FOR TWO PRESSURE VALUES
C    AT EITHER SIDE OF CURRENT INTERVAL.
C
 1100 CONTINUE
C     THIS CHANGE TO ALLOW FOR MONOTONIC INCREASING OR DECREASING TABLES
      TERZ=PINT-XP(1,1) +1.0E-6
      IF(TERZ*(XP(1,1)-XP(1,2))) 1106,1102, 1105
 1106 CONTINUE
      DO 1103 KR=2,KXP1
      TERY=XP(1,KR)-PINT
      IF(TERY*TERZ) 1101,1104,1104
 1101 TERZ=-TERY
 1103 CONTINUE
      GO TO 1120
 1102 CONTINUE
      KR=2
 1104 KR1=KR-1
      XINT=XP(2,KR1)+TERZ/(XP(1,KR)-XP(1,KR1))*(XP(2,KR)-XP(2,KR1))
      GO TO (1152,1153),KL
 1105 CONTINUE
      IF (TERZ-0.001) 1108,1120,1120
 1108 IF (TERZ+0.001) 1120,1120,1110
 1110 TERZ=-1.00*TERZ
      GO TO 1106
 1120 WRITE (6,9105) P10,P11,KL,TERZ,TERY,PINT
      LL=14
      GO TO 500
   30 NSTMT=30
      RETURN
 1142 NSTMT=1142
      RETURN
  145 NSTMT=145
      RETURN
  161 NSTMT=161
      RETURN
   70 NSTMT=70
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LPGCT,NGEO)
      NSTMT=110
      RETURN
C
C   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
C
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,1P9E14.4)
```

```
1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HP,12X,2HCV,12X,2HRA,9X,            SEC33530
    15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,1P9E14.4)                  SEC33540
1003 FORMAT(1H0,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2H*G,         SEC33550
    112X,2HRA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,1P9E14.4)                   SEC33560
9105 FORMAT(1H0,38HSTEP 52 - PRESSURE OUT OF RANGE OF XP ,                SEC33570
    1      16HTABLE.      P1 = ,1PE14.4,3X,5HP2 = ,E14.4,/,7X,7HPROCESS,  SEC33580
    2      24H CONTINUED TO NEXT CASE.,27H  OUTPUT OF LAST ITERATION ,    SEC33590
    3      8HFOLLOWS./T20,3E20.7)                                         SEC33600
9181 FORMAT(1H0,7X,11HNEGATIVE RI)                                        SEC33610
9643 FORMAT(1H1,120X,5HPAGE ,I3,/,1H0,28HREAL TWO-PHASE TWO-COMPONENT     SEC33620
    1,12H NOZZLE FLOW// )                                                 SEC33630
     END                                                                  SEC33640
                 SUBROUTINE SECT4                                         SEC40010
      COMMON TZZZAY                                                       SEC40020
      DIMENSION TZZZAY(11200)                                             SEC40030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP              SEC40050
C     IT MUST BE THE FIRST COMMON BLOCK                                   SEC40060
      COMMON    A       , ABAR    , ALAM    , ALPHAD  , ALPHA   , ALPHMB ,  SEC40070
     1          ALPHS   , AM      , AP      , AS      , AT      , BA     ,  SEC40080
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM     ,  SEC40090
     3          C       , C1      , CAG1    , CAGMB   ,.CAG     , CALMB  ,  SEC40100
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CDLMB   , CDL       SEC40110
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM   ,  SEC40120
     6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM    ,  SEC40130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE   ,  SEC40140
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO   ,  SEC40150
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELY2     SEC40160
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT   ,  SEC40170
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY   ,  SEC40180
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM  ,  SEC40190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2 ,  SEC40200
     4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB      SEC40210
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL    ,  SEC40220
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI    ,  SEC40230
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMBGB  ,  SEC40240
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM   ,  SEC40250
     9          EML     , EMLS    , EMT     , ESO     , FLEEP   , FUX       SEC40260
      COMMON    H       , HJI     , HKAG    , HKBG    , HKGM1   , HKGM2  ,  SEC40270
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS   ,  SEC40280
     2          HLB1    , HLBM    , HLP     , HLPS    , HM      , HMS    ,  SEC40290
     3          HOPE    , HT      , IACV    , IBLA    , IBLX    , IBW    ,  SEC40300
     4          IJH     , INT     , ISET    , ITERO   , K       , K1        SEC40310
      COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KP1    ,  SEC40320
     6          KP      , KTBCT   , KTS     , KKP1    , KKP     , L      ,  SEC40330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPSCT  ,  SEC40340
     8          LSW     , MBU     , MFPO    , MFP     , MGEO    , MM     ,  SEC40350
     9 N      , MOP     , MTHT    , NACV    , NB      , NCLK    , NCTS      SEC40360
      COMMON    NDIAG   , NDS     , NGG     , NIB     , NIS     , NLST   ,  SEC40370
     1          NNA     , NNB     , NNOS    , NNN     , NNP     , NN     ,  SEC40380
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS     ,  SEC40390
     3          P       , P10     , P11     , PAB     , PAMB    , PA     ,  SEC40400
     4          PAS     , PB3     , PBMB    , PBOB    , P30     , PB        SEC40410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL     ,  SEC40420
     6          PLI     , PO      , PS      , PT      , Q       , QID    ,  SEC40430
     7          R1      , RA      , RAS     , RAYO    , RAY     , R3     ,  SEC40440
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , REF    ,  SEC40450
     9          REM     , REMS    , RESLIM  , RESO    , RESZ    , RHOGB     SEC40460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS  ,  SEC40470
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB  ,  SEC40480
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS     ,  SEC40490
     3          RVB     , RV      , RVS     , S       , S1      , S2     ,  SEC40500
     4          S3      , S4      , SA      , SB      , SGN     , SIG       SEC40510
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD   ,  SEC40520
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2   ,  SEC40530
     7          SOP     , SO      , SOSM    , SS      , SZM     , SZO    ,  SEC40540
     8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO    ,  SEC40550
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS      SEC40560
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKT    ,  SEC40570
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM   ,  SEC40580
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR    ,  SEC40590
     3          VBO     , VBDS    , VBM     , VBMSQ   , VB      , VBSQ   ,  SEC40600
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG      SEC40610
```

```
      COMMON    VIALD   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,
     7          VL      , VLSQ    , VLS     , VS      , VSS     , WAGB    ,
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,
     9          WEL     , WGB     , WG      , WGS     , WIM     , WIMS
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,
     1          XINT    , XP      , XS      , XX      , XXA     , YI      ,
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1         C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-60) 1,60,2
    1 CALL DUMP
    2 IF(NSTMT-63) 1,63,1
C
C    END POINT OF THIS INTERVAL OF PRESSURE.
C      COMPUTE CHANGES IN FLOW PARAMETERS THIS INTERVAL.
C
C      ***************** STATEMENT NO. 60  ***********************************
C      ************************************************************************
   60 INT=1
      NSTMT=9999
      VB=ABS(SQRT(VBSQ))
C
C    COMPUTE NEW SLIP FRACTION, S, AND NEW DISTANCE, X.
C
      IF(MPPO-1) 4001,4000,4001
 4000 S=SM
      GO TO 4002
 4001 S=S+DS
 4002 X=X+DX
C
C    COMPUTE CHANGES IN SQUARE OF GAS AND LIQUID VELOCITIES.
C
      DVGSQ=((1.0+(R*S)/(1.0+R))**2)*VBSQ-VGSQ
      DVLSQ=((1.0-S/(1.0+R))**2)*VBSQ-VLSQ
C
C    COMPUTE CHANGES IN GAS AND LIQUID FLOW RATES.
C
      DEMAG=(EMG*WAG*PA)/(WG*P)-EMAG
      DEMBG=(EMG*WBG*PB)/(WG*P)-EMBG
C
C    COMPUTE CHANGES IN GAS AND LIQUID TEMPERATURES.
C
      DTL=(1.0/CLM)*(((HM*DELTM*DX)/(600.*D*RHOLM*VLM))
     1        -(HLAM*DEMAG/EMLM)-(HLBM*DEMBG/EMLM))
      DELT=TG-TL
      DTG=(-1.0/CGM)*((DVGSQ/50072.9)+R*
     1       (CLM*DTL+DP/(5.4039*RHOLM)+DVLSQ/50072.9)+
     2       ((DEMAG+DEMBG)*DELV2)/(50072.9*EMG)+
     3       ((HLA1+CAG1*DELT)*DEMAG+(HLB1+CBG1*DELT)*
     4DEMBG)/EMG)
      IF((1.0 + (R * CLM / CGM)) * ((HM * DX) / (600.0 * D * CLM * RHOL
     1M * VLM)) - 1.) 8075,8076,8076
 8076 DTL = 0.
      DTG = 0.0
      IF(P-0.5*PO) 8075,8074,8074
 8074 CONTINUE
C     THIS LAST TEST ADDED TO DELETE NEXT TEST AT END OF NOZZLE
      ZX=P
C     CHANGE TO SAVE THE LAST P FOR PRINTOUT IN SECT1.
 8075 CONTINUE
C    COMPUTE NEW TEMPERATURES FOR LIQUID AND GAS.
C     IF EITHER IS NEGATIVE PRINT DIAGNOSTIC AND EXIT
C     TO NEXT CASE.
      VGSQ=VGSQ+DVGSQ
      IF(VGSQ) 230,230,231
  230 WRITE (6,9230)
      LL=15
```

```
      GO TO 500
  231 VLSQ=VLSQ+DVLSQ
      IF(VLSQ) 232,232,233
  232 WRITE (6,9232)
      LL=15
      GO TO 500
C
C   COMPUTE NEW VELOCITIES FOR LIQUID AND GAS.
C
C
  233 VG=ABS(SQRT(VGSQ))
      VL=ABS(SQRT(VLSQ))
C
C   COMPUTE RATIO OF GAS FLOW AREA TO LIQUID FLOW AREA.
C
      RA=RV*(VL/VG)
C
C   COMPUTE NEW LIQUID AND GAS FLOW RATES.
C
      EMAG=EMAG+DEMAG
      EMBG=EMBG+DEMBG
      DELV2=VGSQ-VLSQ
C
C   SET UP INITIAL QUANTITIES FOR NEXT END-POINT.
C
      DTL1=DTL
      DTG1=DTG
      HLA1=HLA
      HLB1=HLB
      DELT=TG-TL
      CAG1=CAG
      CBG1=CBG
      VS=S*VB
C
C   INTERPOLATE INTO SURFACE TENSION TABLE AT THIS LIQUID
C    TEMPERATURE.
C
      N=18
      NN=18
      CALL INTRP(SIG,N,TL,P)
      LL=16
      IF(N) 161,161,240
C   IF DROPLET BREAKUP OPTION SPECIFIED, COMPUTE DROPLET
C    DIAMETER.
  240 IF(MEU-1) 243,238,243
  238 D2=(.3174*SIG)/(RHOG*VS**2)
      IF(D-D2) 243,243,239
  239 D=D2
C
C   COMPUTE CHANGE IN NOZZLE CROSS-SECTIONAL AREA SINCE
C    LAST END-POINT.
C
  243 DA=144.0*EMG*(1.0/(RHOG*VG)+R/(RHOL*VL))-A
C
C   COMPUTE MEAN AREA BETWEEN THIS AND PREVIOUS ENDPOINT.
C
      AM=A+DA/2.0
C
C   COMPUTE PRESENT AREA
C
      A=A+DA
      IF(MGEO-1)67,68,67
C
C   COMPUTE RADII AND DISTANCE FROM AXIS TO WALL OF
C    CIRCULAR NOZZLE.
C     ***************** STATEMENT NO. 67 ******************************
C     *****************************************************************
   67 DYO=SQRT(A/3.1416)-YO
      RCM=YO+DYO/2.0
      DRO=DYO
      YO=YO+DYO
      RO=YO
```

```
      WIM=0.0
      DELI =0.0
      DELSI=0.0
      RDELIM=0.0
      CFIM=0.0
      TWIM =0.0
      GO TO 69
C
C   COMPUTE GEOMETRY OF ANNULAR NOZZLE AND BOUNDARY-LAYER
C    GROWTH AND SHEAR FOR INNER WALL.
C
   68 RAX=RAXO-X*SIN(PHI)
      IF(RAX**2-(A*COS(PHI))/(2.0*3.1416)) 241,242,242
  241 WRITE (6,9241)
      LL=17
      GO TO 500
  242 DRI=SQRT(RAX**2-(A*COS(PHI))/(2.0*3.1416))-RI
      DRO=SQRT(RAX**2+(A*COS(PHI))/(2.0*3.1416))-RO
      RIM=RI+DRI/2.0
      RI=RI+DRI
      ROM=RO+DRO/2.0
      RO=RO+DRO
      DYI=(RAX-RI)/(COS(PHI))-YI
      DYO=(RO-RAX)/(COS(PHI))-YO
      YI=YI+DYI
      YO=YO+DYO
C
C   COMPUTE ANGLE OF NOZZLE INNER WALL RELATIVE TO AXIS.
C
      WIM=(ATAN(DYI/DX))
      WIM=WIM*57.29578
  246 DTHI=0.5*CFIM*((AM*BM)/(1.0+RM))*DX-  THIM*
     1      ((1.143*DVBSQ)/VBMSQ-DA/AM+DRI/RIM)
      TWIM=(CFIM*RHOL*VLSQ)/(6559.6*(1.0+RA))
      THI=THI+DTHI
      DELI=10.286*THI
      DELSI=1.2857*THI
   69 DTHO=0.5*CFOM*((AM*BM)/(1.0+RM))*DX-THOM*
     1      ((1.143*DVBSQ)/VBMSQ-DA/AM+DRO/ROM)
      TWOM=(CFOM*RHOL*VLSQ)/(6559.6*(1.0+RA))
      THO=THO+DTHO
      DELO=10.286*THO
      DELSO=1.2857*THO
C
C   COMPUTE ANGLE OF NOZZLE OUTER WALL RELATIVE TO AXIS.
C
      WOM=ATAN(DYO/DX)
      WOM=57.29578*WOM
C
C   COMPUTE MEAN VELOCITY (INCLUDING BOUNDARY LAYER).
C
  251 VBD=VB*(1.0-((2.0*3.1416)/A)*
     1      (RO*THO+RI*THI))
      GO TO 61
C
C   IF AREA LESS ZERO, NOZZLE IS CONVERGING AND THROAT HAS
C    NOT JUST BEEN PASSED. IF NOT, NOZZLE THROAT MAY
C    HAVE JUST BEEN PASSED.
C
   61 IF(A-AT)66,62,62
C
C   ADVANCE STEP COUNT AND RETURN TO STEP 30 IF MAXIMUM
C     STEP COUNT NOT REACHED.
C
   62 NNS=NNS+1
      IF(NNS-NS) 30,260,260
C
C   INITIALIZE TB AND COUNTERS AND GO TO STEP 140 TO
C     COMPUTE BARRED QUANTITIES.
C
  260 TB=TL
      NNS=0
```

```
      NNB=1
      GO TO 140
C
C   OUTPUT HAS JUST BEEN PRINTED.  RETURN TO STEP 30
C     IF ITERATION IS NOT COMPLETED.
C
   63 NNP=NNP+1
      NSTMT=3999
      IF(NNP-NP)30,64,64
C
C
   64 PL1(1)=XS
      PL1(2)=PS
      PL1(3)=RS
      PL1(4)=VES
      PL1(5)=AS
      PL1(6)=TGS
      PL1(7)=TLS
      PL1(8)=VGS
      PL1(9)=VLS
      PL1(10)=1.0
C     WRITE (18) PL1
      MM=MM+1
  264 CALL OUTPUT (NNN,LPGCT,MGEO)
      GO TO 110
   66 AT=A
      PT=P
      XS=X
      PS=P
      TLS=TL
      VGS=VG
      RS=R
      VBS=VB
      AS=A
      TGS=TG
      VLS=VL
      VSS=VS
      SS=S
      DD=D
      RVS=RV
      RAS=RA
      ALPHS=ALPHA
      BETAS=BETA
      EMGS=EMG
      EMLS=EML
      RHOGS=RHOG
      RHOLS=RHOL
      WAGS=WAG
      WBGS=WBG
      WGS=WG
      PAS=PA
      PBS=PB
      HLAS=HLA
      HLBS=HLB
      SIGS=SIG
      CGMS=CGM
      CLMS=CLM
      VIGMS=VIGM
      VILMS=VILM
      HKGMS=HKGM
      REMS=REM
      CDMS=CD
      HMS=HM
      YOS=YO
      WOMS=WOM
      THOS=THO
      DELOS=DELO
      DLSOS=DELSO
      RDOMS=RDELOM
      CFOMS=CFCM
      TWOMS=TWCM
      VBDS=VBD
```

```
      YIS=YI
      WIMS=WIM
      THIS=THI
      DELIS=DELI
      DLSIS=DELSI
      RDIMS=RDELIM
      CFIMS=CFIM
      TWIMS=TWIM
      GO TO 62
   30 NSTMT=30
      RETURN
  140 NSTMT=140
      RETURN
  161 NSTMT=161
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LPGCT,MGEO)
  110 NSTMT=110
      RETURN
 9230 FORMAT(1H0,7X,14HNONPOSITIVE VG)
 9232 FORMAT(1H0,7X,14HNONPOSITIVE VL)
 9241 FORMAT(1H0,7X,11HNEGATIVE RI)
      END
                      SUBROUTINE SECT5
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3          C       , C1      , CAG1    , CAGMB   , CAM     , CALMB   ,
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
     6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,
     9          DELOS   , DELSI   , DELSO   , DELTA   , DELT    , DELV2
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DIST    ,
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,
     4          DSPES   , DS      , DSX1    , DSX2    , DTG1    , DTG3
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DY1     ,
     7          DYO     , EB      , EDG     , EMAGB   , EMAG    , EMBGB   ,
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLH    ,
     9          EML     , EMLS    , EMT     , ESO     , FLEXP   , FUK
      COMMON    H       , HJT     , HKAG    , HKBG    , HKGM1   , HKGM2   ,
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,
     3          HOPE    , HT      , IACV    , ITLW    , IBLK    , IBW     ,
     4          IJH     , INT     , ISFT    , IZERO   , K       , K1
      COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KR1     ,
     6          KR      , KTBCT   , KT3     , KXP1    , KXP     , L       ,
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT   ,
     8          LSW     , MDU     , MFFO    , MFP     , MGEO    , MM      ,
     9 N      , MOP     , MTMT    , NACV    , NB      , NCLK    , NCPS
      COMMON    NDIAG   , NDS     , NGS     , NIB     , NIS     , NLSP    ,
     1          NNA     , NNB     , NNDS    , NNN     , NNP     , NN      ,
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,
     4          PAS     , PBB     , PBMB    , PROB    , PBO     , PB
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,
     6          PL1     , PO      , PS      , PT      , Q       , QID     ,
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , REF     ,
     9          REM     , REMS    , RESLIM  , RESO    , REZZ    , RHOGB
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,
     1          RIN     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,
```

```
     4         S3      , S4     , SA     , SB     , SGN    , SIG    ,
      COMMON   SIGS    , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,
     6         SMLE    , SMLP   , SMLG   , SM     , SOJ1   , SOJ2   ,
     7         SOP     , SO     , SOSM   , SS     , SSM    , SZO    ,
     8         T       , TB     , TBRAY  , TBRAY1 , TGHB   , TGO    ,
     9         TG      , TGS    , THIM   , THIO   , THI    , THIS
      COMMON   THOM    , THOO   , THO    , THOS   , TK     , TKI    ,
     1         TLMB    , TLO    , TL     , TLS    , TST    , TWIM   ,
     2         TWIMS   , TWOM   , TWOMS  , V1     , V2     , VAR    ,
     3         VBD     , VBDS   , VBM    , VBMSQ  , VB     , VBSQ   ,
     4         VBS     , VGO    , VG     , VGSQ   , VGS    , VIAG
      COMMON   VIALB   , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,
     6         VIGMS   , VILB   , VILM   , VILMS  , VLM    , VLO    ,
     7         VL      , VLSQ   , VLS    , VS     , VSS    , WAGB   ,
     8         WAG     , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,
     9         WBL     , WGB    , WG     , WGS    , WIM    , WIMS
      COMMON   WOM     , WOMS   , X      , X10    , X11    , XCLK   ,
     1         XINT    , XP     , XS     , XX     , XXA    , YI     ,
     2         YIS     , YO     , YOS    , ZZZ    , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1        C(6),AP(2,75),XXA(9),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-70) 1,70,2
    1 CALL DUMP
    2 IF(NSTMT-100) 1,100,3
    3 IF(NSTMT-1400) 1,1400,1
C     *************** STATEMENT NO. 70 ********************************
C     *****************************************************************
C
C
C   DELTA S ITERATION ROUTINE.
C
   70 CONTINUE
      NSTMT=9999
16004 CONTINUE
      IF(S+DS1)25070,25060,25070
25060 CONTINUE
      S=1.0E-6
C     FOLLOWING STATEMENT SIMPLIFIED BY UNIVAC.
C     SO=-SIGN(1.0,DP*ZZZ) ... ETC.
25070 CONTINUE
      IF(MOP) 2470,2399,2470
 2470 CONTINUE
      DSMIN=1.0E-6-2.0*(S+(1.0+B)/B)
      DSMAX=1.0+B-1.0E-6
      DSLIM=DSMIN
      IF(DP) 3000,3010,3010
 3000 CONTINUE
      DSLIM=DSMAX
 3010 CONTINUE
      IJH=1
      SM=0.0
      GO TO 16000
 3030 CONTINUE
      IJH=2
      RESO=SOSM
      SMJ1=SM
      SOJ1=SO
      SM=DSLIM
      GO TO 16000
 3031 CONTINUE
      PSLIM=SOSM
      SMJ2=SM
      SOJ2=SO
      IF(RESO*PSLIM) 3090,3060,3060
 3060 CONTINUE
      WRITE (6,3061) DSLIM,DP
      GO TO 3090
 3071 CONTINUE
      RESZ=SOSM
```

```
      SZO=SO
      SZM=SM
      HOPE=RESC*RESZ
      IF(HOPE) 3080,3085,3085
 3080 CONTINUE
      RSLIM=RESZ
      DSLIM=SZM
      SOJ2=SZO
      GO TO 3090
 3085 CONTINUE
      RESO=RESZ
      SMJ1=SZM
      SOJ1=SZO
 3090 CONTINUE
      SM=(SMJ1+DSLIM)/2.0
      IJH=3
16000 CONTINUE
      IF(ABS(SM)-SMIN) 1390,1390,1391
 1390 CONTINUE
      SM=-SIGN(SMIN,DP)
 1391 AM=1.0+(R*SM)/(1.0+R)
      BM=1.0-SM/(1.0+R)
      DVBSQ=(-V1/AM)-(V2/BM)
      VBMSQ=VBSQ+DVBSQ/2.0
C
C     WRITE DIAGNOSTIC IF VBM NON-POSITIVE.
C
      IF(VBMSQ) 1250,1250,1251
 1250 CONTINUE
      WRITE (6,9250) SM,AM,BM,V1,V2,VBSQ,DVBSQ,R,VBMSQ
      LL=18
      GO TO 1482
C
C     COMPUTE VBM
C
 1251 VBM=SQRT(VBMSQ)
      REM=R1*VBM*ABS(SM)
      IF(REM-.000001) 1258,1258,1259
 1258 CD=2.4E07
      GO TO 71
 1259 IF(REM-0.1) 1260,1260,1263
 1263 IF(REM-20000.) 1261,1264,1264
 1264 CD=0.4569
      GO TO 71
 1260 CD=24.0/REM
      GO TO 71
 1261 CD=EXP(3.271-0.8893*(ALOG(REM))+0.03417*
     1((ALOG(REM))**2)+.001443*((ALOG(REM))**3))
   71 CONTINUE
C     ***************** STATEMENT NO. 80  ********************************
C     ********************************************************************
C
C     OPTIMUM SM IS TO BE USED.
C
   80 IF(REM-.1611) 1380,1380,1381
 1380 CDP=1.0
      GO TO 1384
 1381 IF(REM-4709.) 1382,1382,1383
 1382 CDP=1.1137+.06934*(ALOG(REM))+.004329*((ALOG(REM))**2)
      GO TO 1384
 1383 CDP=2.0
 1384 SMLC=(C1*(BM**2))/(VBMSQ*CD )
      SMLD=(RHOL*(BM**2))/(RHOG*(AM**2))
      SMLG=((RHOL*(BM**2))/(RHOG*AM*(1.0+R)))+
     1     ((R*BM)/(1.0+R))-1.0
      SMLP=SMLD*(((2.0*AM)/(R*BM))+1.0)+1.0
C     D-1 TO D                                JHH 8/19/66
      ZZZ=SMLP*SMLG*SM+SMLD*CDP
      SO = -SIGN(1.0,DP*ZZZ)
      C2 = 2.0*SMLG*SMLD
      C2 = SMLC*ZZZ/C2
      IF(C2.LT.0.0) C2=ABS(C2)
```

```
      C2 = C2**0.33333
      SO = SO*C2
      SOSM = SO-SM
   81 IF(ABS(SO-SM)-ESO)1481,1481,1482
 1481 NIS=NNSO
      NNSO=0
      REWIND 16
      GO TO 82
C*********THIS IS TO BYPASS ITERATION COUNTER DURING PLOTTING IJH = 4
 1482 CONTINUE
11482 NNSO = NNSO + 1
16060 IF (NNSO-NSO)  1483,1483,1490
C
C  STORE THIS VALUE OF DS1 AND WRITE DS1 ARRAY IF FULL.
C
 1483 CONTINUE
C*********DEBUGGING AID FOR BINARY CUT CONVERGENCE
      DSRAY(KDS)=22222222.
      DSRAY(KDS+1)  =  SMJ1
      DSRAY(KDS+2)  =  SOJ1
      DSRAY(KDS+3)  =  RESO
      DSRAY(KDS+4)  =  SM
      DSRAY(KDS+5)  =  SO
      DSRAY(KDS+6)  =  SOSM
      DSRAY(KDS+7)  =  DSLIM
      DSRAY(KDS+8)  =  SOJ2
      DSRAY(KDS+9)  =  RSLIM
      KDS = KDS + 10
      IF(KDS  -  100) 16003,16003,1484
 1484 WRITE  (16) DSRAY
      KDSCT=KDSCT+1
      DO 1486  I=1, 100
      DSRAY(I)=0.0
 1486 CONTINUE
      KDS=1
16003 CONTINUE
      GO TO  (3030,3031,3071),IJH
C*****END OF BINARY CUT CONVERGENCE ROUTINE
C
C   NO CONVERGENCE ON DS  -  PRINT DIAGNOSTIC AND GET ALL
C      PREVIOUS VALUES OF DS FROM TAPE 16  AND TEMPORARY STORAGE IN
C      DSRAY.   PRINT THEM ANDEXIT TO DIAGNOSTIC ROUTINE.
C
 1490 REWIND 16
      NSTMT=9999
      WRITE (6,9490)
 1491 IF(KDSCT)1493,1493,1492
 1492 READ (16) DSRAY1
      WRITE (6,9491)  (DSRAY1(I),I=1, 100)
      KDSCT=KDSCT-1
      GO TO 1491
 1493 WRITE  (6,9491)  (DSRAY(I),I=1,KDS)
      KDS=1
      KDSCT=0
      DO 1495  I=1, 100
      DSRAY(I)=0.0
 1495 CONTINUE
      LL=18
      REWIND 16
      GO TO 500
C
C   OPTIMIZE DS AND DX.
C
   82 IF(MFPO-1)2382,2381,2382
 2381 DS=0.0
      S=SO
      MFPO=0
      GO TO 83
 2382 DS=SO-SOP
   83 SOP=SO
      DX=(D/(0.75*RHOG*ABS(SM)*SM*CD*VBMSQ))
     1      *(4633.04*DP+((BM**2)*RHOL*DVBSQ)/2.0)
```

```
     2        +((BM*RHOL*VBMSQ)/(1.0+R))*(((2.0*SM*DT)/(1.0+R))-DS))
 100  DS1=DS
      NSTMT=9999
      VBSQ=VBSQ+DVBSQ
      IF(VBSQ) 300,300,301
 300  WRITE (6,9300)
      LL=19
      GO TO 500
C
C     STORE M+DPOINT QUANTITIES FOR NEXT END-POINT.
C
 301  EMLM=EML
      RHOLM=RHOL
      DELTM=TG-TL
      VLM=BM*VBM
      HLAM=HLA
      HLBM=HLB
      RM=R
C
C     DETERMINE HEAT TRANSFER COEFFICIENT.   SEGMENTS ARE NOT
C        CONTINUOUS AT JUNCTIONS.
C
      IF(REM-1.0) 304,304,305
 304  HM=(24.0*HKGM)/D
      GO TO 308
 305  IF(REM-25.0) 306,306,307
 306  HM=3600.*CGM*RHOG*(ABS(SM))*VBM*
     1      ((2.2/REM)+(.48/(SQRT(REM))))
      GO TO 308
 307  HM=(4.44*HKGM*(REM**.6))/D
C
C     COMPUTE MEAN BOUNDARY-LAYER PARAMETERS FOR CIRCULAR NOZZLE
C        OR OUTER WALL OF ANNULAR NOZZLE.
C
 308  THOM=THO+DTHO/2.0
      DELOM=10.286*THOM
      RDELOM=(300.*RHOL*VL*DELOM)/VILM
      IF(RDELOM.LT.0.0) RDELOM=ABS(RDELOM)
      CFOM=.208/((ALOG10(RDELOM)+.425)**2.584)
      IF(MGEO) 309,30,309
 309  THIM=THI+DTHI/2.0
      DELIM=10.286*THIM
      RDELIM=(300.*RHOL*VL*DELIM)/VILM
      CFIM=.208/((ALOG10(RDELIM)+.425)**2.584)
  30  NSTMT=30
      RETURN
2399  NSTMT=2399
      RETURN
 500  NDIAG=1
      CALL OUTPUT(NNN,LPGCT,MGEO)
      NSTMT=110
      RETURN
9250  FORMAT(1H0,7X,15HNONPOSITIVE VBM/(1H ,9X,1P5E15.6))
9300  FORMAT(1H0,7X,14HNONPOSITIVE VB)
9490  FORMAT(1H0,7X,24HCOULD NOT CONVERGE ON DS,//)
9491  FORMAT(1H ,1P10E13.4)
3061  FORMAT(1H0,38HLIKE SIGN RESIDUES IN INTERVAL 0 TO    ,1PE12.4,
     19HFOR DP = ,E15.4)
      END
                      SUBROUTINE SECT6
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
     6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,
```

```
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2   ,
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT    ,
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,
     4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB    ,
      COMMON    DTG     , DTHI    , DTHO    , DTLI    , DTLB    , DTL     ,
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI     ,
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMBGB   ,
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,
     9          EML     , EMLS    , EMT     , ESO     , FLEEP   , FUX     ,
      COMMON    H       , HJI     , HKAG    , HKBG    , HKGM1   , HKGM2   ,
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,
     3          HOPE    , HT      , IACV    , IBEW    , IBLX    , IBW     ,
     4          IJH     , INT     , ISET    , IZERO   , K       , K1      ,
      COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KR1     ,
     6          KR      , KTBCT   , KTB     , KXP1    ,.KXP     , L       ,
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT   ,
     8          LSW     , MBU     , MFPO    , MPP     , NGEO    , MM      ,
     9 N      , MOP     , MTHT    , NACV    , NB      , NCLK    , NCTS    ,
      COMMON ' NDIAG   , NDS     , NGG     , NIB     , NIS     , NLST    ,
     1          NNA     , NNB     , NNDS    , NNN     , NNP     , NN      ,
     2          NNSOO   , NNSO    , NNS     , NP      , NSC     , NS      ,
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,
     4          PAS     , PBB     , PBMB    , PBOB    , PBO     , PB      ,
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      ,
     6          PL1     , PO      , PS      , PT      , Q       , QID     ,
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , REF     ,
     9          REM     , REMS    , RESLIM  , RESO    , RESS    , RHOGB   ,
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,
     4          S3      , S4      , SA      , SB      , SGN     , SIG     ,
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,
     7          SOP     , SO      , SOSM    , SS      , SZM     , SZO     ,
     8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO     ,
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS    ,
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKT     ,
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAW     ,
     3          VBD     , VBDS    , VBM     , VBMSQ   , VB      , VBSQ    ,
     4          VGS     , VGO     , VG      , VGSQ    , VGS     , VIAG    ,
      COMMON    VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,
     7          VL      , VLSQ    , VLS     , VS      , VSS     , WAGB    ,
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,
     9          WBL     , WGP     , WG      , WGS     , WIM     , WIMS    ,
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,
     1          XINT    , XP      , XS      , XX      , XXA     , YI      ,
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1       C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-140) 1,140,2
    1 CALL DUMP
    2 IF(NSTMT-2399) 1,2399,1
C
C     COMPUTE  BARRED QUANTITIES AND ITERATE FOR CONVERGENCE ON TB.
C     GET INTERPOLATED PBO FROM TABLE FOR THIS TB.
C
  140 N=9
      NSTMT=9999
  339 NN=9
      CALL INTSP(PBOB,N,TB,P)
```

```
      IF(N) 318,318,320
  318 LL=20
  319 WRITE (6,9318) HT(NN),TB,P
      GO TO 500
C
C      COMPONENT A.   PRINT DIAGNOSTIC IF SUFFICIENTLY CLOSE TO ZERO.
C
  320 IF(ABS(1.0-H*PBOB)-.0001) 321,321,323
  321 WRITE (6,9320)
      LL=20
      GO TO 500
C
C   COMPUTE PARTIAL PRESSURE OF COMPONENT A AND B AND
C      PRINT DIAGNOSTIC IF EITHER NONPOSITIVE.
C
  323 PAB=(P-PBOB)/(1.-(H*PBOB))
      IF (PAB) 310,322,322
  322 PBB = P-PAB
      IF(PBB) 312,9323,9323
C
C   INTERPOLATE INTO MOLECULAR WEIGHT TABLES FOR A AND B
C      AT THIS TEMPERATURE AND PRESSURE.
C
 9323 N=3
      NN=3
      CALL INTERP(WAGB,N,TB,PAB)
      IF(N) 325,325,327
  325 LL=22
      WRITE (6,9318) HT(NN),TB,PAB
      GO TO 500
  327 N=4
      NN=4
      CALL INTERP(WBGB,N,TB,PBB)
      IF(N) 329,329,330
  329 LL=23
      WRITE (6,9318) HT(NN),TB,PBB
      GO TO 500
  310 WRITE (6,9310)
      LL=20
      GO TO 500
  312 WRITE (6,9312)
      LL=21
      GO TO 500
C
C   COMPUTE MEAN MOLECULAR WEIGHT.
C
  330 WGB=((WAGB*PAB)+(WBGB*PBB))/P
C
C   COMPUTE ALPHA AND BETA.
C
      ALPHAB=((WAL/WBL)*H*PAB)/
     1       (1.0+((WAL/WBL)-1.0)*H*PAB)
      BETAB=(WBGB*PBB)/(WGB*P)
C
C   CHECK DENOMINATOR OF EQUATION FOR R AND PRINT
C      DIAGNOSTIC IF SUFFICIENTLY CLOSE TO ZERO.
C
      TK=(1.0-(1.0+RC)*ALPHAB)
      TKT=ABS(TK)
      IF(TKT-.0001) 333,335,335
  333 WRITE (6,9333)
      LL=24
      GO TO 500
C
C   COMPUTE BARRED FLOW PARAMETERS.
C
  335 RB=(RC-(1.0+RC)*BETAB)/TK
      DEMGB=(EMT/(1.0+RB))-EMG
      EMGB=EMG+DEMGB
      EMLB=RB*EMGB
      DEMAGB=((EMGB*WAGB*PAB)/(WGB*P))-EMAG
      DEMBGB=((EMGB*WBGB*PBB)/(WGB*P))-EMBG
```

```
      EMAGB=EMAG+DEMAGB
      EMBGB=EMBG+DEMBGB
      DTGB=TB-TG
      TLMB=(TL+TB)/2.0
      TGMB=(TG+TB)/2.0
      PAMB=(PA+PAB)/2.0
      PBMB=(PB+PBB)/2.0
C
C    INTERPOLATE INTO SPECIFIC HEAT TABLES FOR
C          CALMB  -  SPECIFIC HEAT - LIQUID A
C          CBLMB  -  SPECIFIC HEAT - LIQUID B
C          CAGMB  -  SPECIFIC HEAT - GAS A
C          CBGMB  -  SPECIFIC HEAT - GAS B
C
      N=5
      NN=5
      CALL INTRP(CALMB,N,TLMB,P )
      IF(N) 340,340,341
  340 WRITE (6,9136) HT(NN),TLMB,P
      LL=25
      GO TO 500
  341 N=6
      NN=6
      CALL INTRP(CBLMB,N,TLMB,P)
      IF(N) 340,340,343
  343 N=1
      NN=1
      CALL INTRP(CAGMB,N,TGMB,PAB)
      IF(N) 344,344,345
  344 LL=25
      WRITE (6,9136) HT(NN),TGMB,PAB
      GO TO 500
  345 N=2
      NN=2
      CALL INTRP(CBGMB,N,TGMB,PBB)
      IF(N) 346,346,347
  346 LL=25
      WRITE (6,9136) HT(NN),TGMB,PBB
      GO TO 500
  347 ALPHMB=(ALPHA+ALPHAB)/2.0
      BETAMB=(BETA+BETAB)/2.0
      CLMB=(ALPHMB*CALMB)+(1.0-ALPHMB)*CBLMB
      CGMB=(1.0-BETAMB)*CAGMB+BETAMB*CBGMB
      DTLB=(-1.0/(EB*CLMB))*((CGMB*DTGB)+
     1      ((VBSQ-VG**2+EB*( VBSQ-VL **2))/50072.9)+
     2      ((DEMAGB/EMGB)*(HLA+CAG*(TG-TL)))+
     3      ((DEMBGB/EMGB)*(HLB+CBG*(TG-TL)))+
     4      ((DEMGB/EMGB)*(((VG**2)-(VL**2))/50072.9)))
C
C    TEST FOR CONVERGENCE ON TB.
C
      IF((ABS((TB-TL)-DTLB))-EB) 141,141,350
  350 NNB=NNB+1
      IF(NNB-NE) 351,351,354
C
C    SAVE THIS VALUE OF TB FOR POSSIBLE NON-CONVERGENCE.
C
  351 TB=TL+DTLB
      TBRAY(KTB)=TB
      KTB=KTB+1
      IF(KTB-100) 140,140,352
  352 WRITE (14) TBRAY
      DO 353 I=1,100
      TBRAY(I)=0.0
  353 CONTINUE
      KTB=1
      KTBCT=KTBCT+1
       GO TO 140
C
C    NO CONVERGENCE ON TB AND ITERATION MAXIMUM REACHED.
C        PRINT DIAGNOSTIC AND ALL VALUES OF TB FOUND.
C
```

```
  354 WRITE (6,9352)
  399 IF(KTBCT)403,403,400
  400 READ (14) TBRAY1
      WRITE (6,9491) (TBRAY1(I),I=1,100)
      KTBCT=KTBCT-1
      GO TO 399
  403 WRITE (6,9491) (TBRAY(I),I=1,KTB)
C
C   CLEAR TB SAVE ARRAY.
C
      KTB=1
      KTBCT=0
      DO 405 I=1,100
      TBRAY(I) = 0.0
  405 CONTINUE
      LL=26
      GO TO 500
C   STORE NUMBER OF ITERATIONS REQUIRED TO CONVERGE ON TB.
C
C
C     *************** STATEMENT NO. 140 ***********************************
C     ***********************************************************************
  141 NIB=NNB
      NNB=1
C
C   COMPUTE DENSITY OF GAS MIXTURE.
C
      RHOGB=(WGB*P)/(10.732*TB)
C
C   INTERPOLATE FOR DENSITIES OF LIQUIDS A AND B.
C
      N=10
      NN=10
      CALL INTRP(ROALB,N,TB,P)
      LL=27
      IF(N) 319,319,360
  360 N=11
      NN=11
      CALL INTRP(ROBLB,N,TB,P)
      LL=27
      IF(N) 319,319,363
C
C   COMPUTE DENSITY OF LIQUID MIXTURE.
C
  363 RHOLB=1.0/((ALPHAB/ROALB)+((1.0-ALPHAB)/(ROBLB)))
      ABAR=((144.0*EMGP)*(1.0/RHOGB+RB/RHOLB))/VB
      RVB=RHOLB/(RB*RHOGB)
      Q=(RHOLB*ABAR*VB)/(144.0*EMLB)
C
CC    INTERPOLATE INTO VISCOSITY TABLES FOR LIQUID A AND B.
C
      N=14
      NN=14
      CALL INTRP(VIALB,N,TB,P)
      LL=28
      IF(N) 319,319,366
  366 N=15
      NN=15
      CALL INTRP(VIBLB,N,TB,P)
      IF(N) 369,369,370
  369 LL=28
      GO TO 319
  370 VILB=ALPHAB*VIALB+(1.0-ALPHAB)*VIBLB
      REF=(8617.2*EMLB)/(VILB*(SQRT(ABAR)))
C  ENTER CURRENT VALUES OF A AND P INTO A VS P TABLE
C
  529 NSTMT=529
       RETURN
C
C     ***********************************************************************
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C   FIND GOOD APPROXIMATION FOR DS1 TO USE IN SUCCESSIVE
```

```
C       SUBSTITUTION ROUTINE AT STEP 90.
C
 2399   KDSCT=0
        NSIMT=9999
        IBLW=0
        KDS=1
        NNDS=0
        SGN=0.5
        DSMIN=1.0E-6-2.0*(S+(1.0+R)/R)
        DSMAX=1.0+R-1.0E-6
12399   CONTINUE
        DS1=DSMIN
        IBW=1
        GO TO 5000
 2401   CONTINUE
        DSX1=DS1
        DSRES1=DSRES
        DS1=DSMAX
        IBW=2
        GO TO 5000
 2402   CONTINUE
        DSX2=DS1
        DSRES2=DSRES
        IF(IBLX) 12402,2403,12402
12402   CONTINUE
        DS1=DSAVE
        GO TO 12403
 2403   CONTINUE
        DS1=DSX1-DSRES1*(DSX2-DSX1)/(DSRES2-DSRES1)
        IBLX=1
12403   CONTINUE
        IBW=3
        GO TO 5000
 2404   CONTINUE
        IF(DSRES*DSRES1) 2405,2406,2406
 2405   CONTINUE
        DSRES2=DSRES
        DSX2=DS1
        SGN=-1.0*SGN
        GO TO 2407
 2406   CONTINUE
        DSRES1=DSRES
        DSX1=DS1
 2407   CONTINUE
        IF(SGN) 12407,2408,2408
12407   CONTINUE
        DS1=DSX2
        GO TO 2409
 2408   CONTINUE
        DS1=DSX1
 2409   CONTINUE
        DS1=DS1+SGN
        IF(DS1-DSMAX)2410,2410,5060
 2410   CONTINUE
        IF(DS1-DSMIN)5060,12410,12410
12410   CONTINUE
        IBW=4
        GO TO 5000
12411   CONTINUE
        IF(SGN) 12414,12412,12412
12412   CONTINUE
        IF(DSRES*DSRES2) 2406,12413,12413
12413   CONTINUE
        DSRES2=DSRES
        DSX2=DS1
        GO TO 12416
12414   CONTINUE
        IF(DSRES*DSRES1) 12417,12415,12415
12415   CONTINUE
        DSRES1=DSRES
        DSX1=DS1
12416   CONTINUE
```

```
      SGN=SGN/10.0
      IBLW=IBLW+1
      IF(IBLW-5) 2403,2403,5060
12417 CONTINUE
      DSRES2=DSRES
      DSX2=DS1
      GO TO 2409
C
C       EVALUATE DS FOR GIVEN DS1.   TEST FOR CONVERGENCE
C
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
 5000 CONTINUE
      SM=S+DS1/2.0
      AM=1.0+(R*SM)/(1.0+R)
      BM=1.0-SM/(1.0+R)
      DVBSQ=(-V1/AM)-(V2/BM)
      VBMSQ=VBSQ+DVBSQ/2.0
      IF(VBMSQ)6000,5001,5001
 6000 CONTINUE
      WRITE (6,3001) SM,S,DS1,AM,R,BM,DVBSQ,V1,V2,VBMSQ,VBM
 5001 CONTINUE
      VBM=SQRT(VBMSQ)
      REM=R1*VBM*ABS(SM)
      IF(REM-.000001)5015,5015,5005
 5005 IF(REM-0.1)5020,5020,5010
 5010 IF(REM-20000.)5030,5025,5025
 5015 CD=2.4E07
      GO TO 5035
 5020 CD=24.0/REM
      GO TO 5035
 5025 CD=0.4553
      GO TO 5035
 5030 CD=EXP(3.271-0.8893*(ALOG(REM))+0.03417*
     1((ALOG(REM))**2)+.001443*((ALOG(REM))**3))
 5035 CONTINUE
     DSMP=-((S1*ABS(SM)*SM*CD)/BM)+(S2/(BM*VBMSQ))
     1+((S3*BM*DVBSQ)/VBMSQ)+S4*SM
      DSRES=DSMP-DS1
      IF(ABS(DSRES)-EDS)91,91,5040
 5040 DSRAY(KDS)=DS1
      DSRAY(KDS+1)=DSRES
      KDS=KDS+2
      IF(KDS-100)5055,5055,5045
 5045 WRITE (16) DSRAY
      KDSCT=KDSCT+1
      DO 5050 L=1,100
 5050 DSRAY(L)=0.0
      KDS=1
 5055 NNDS=NNDS+1
      IF(NNDS-NDS) 5070,5070,5060
 5060 WRITE (6,5065) DSX1,DSX2,DS1,DSRES1, DSRES2,DSRES
      LL=18
      GO TO 1490
 5070 CONTINUE
      GO TO (2401,2402,2404,12411,2405,2407,2409),IBW
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C   COMPUTE NEXT APPROXIMATION TO DS.
C
   91 NIS=NNDS
      IBLX=1
      DS=DS1
      DSAVE=DS1
      NNDS=0
      GO TO 100
 1490 NSTMT=1490
      RETURN
  100 NSTMT=100
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LPGCT,NGEO)
```

```
      NSTMT=110
      RETURN
 5065 FORMAT(1H0,7X,51HNO DS CONVERGENCE.  COULD DETECT NO SIGN CHANGE
     1IN ,34HRESIDUALS OF F(DS).  VALUES FOLLOW  /(10X,1P6E15.6))
 9001 FORMAT(1H0,10X,20HNEGATIVE VBMSQ,SECT6 /(1X,1P8E15.6))
 9136 FORMAT(1H0,7X,17HOUTSIDE RANGE OF  , A6,7H TABLE.,5X,
     14HT = ,1PE12.4,5X,4HP = ,E12.4)
 9310 FORMAT(1H0,7X,12HNEGATIVE PAB)
 9312 FORMAT(1H0,7X,12HNEGATIVE PBB)
 9318 FORMAT(1H0,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,
     14HT = ,1PE12.4,5X,4HP = ,E12.4)
 9320 FORMAT(1H0,7X,12HINFINITE PAB)
 9333 FORMAT(1H0,7X,14HNONPOSITIVE PB)
 9352 FORMAT(1H0,7X,24HCOULD NOT CONVERGE ON TB)
 9491 FORMAT(1H ,1P10E13.4)
      END
                  SUBROUTINE THROAT
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
     6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,
     9          DELOS   , DELSI   , DELSO   , DELPM   , DELP    , DELV2
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DIST    ,
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    ,
     2          DPI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,
     4          DSRES   , DS      , DSX1    , DSX2    , DTG1    , DTGB
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     ,
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DYI     ,
     7          DYO     , EB      , EBS     , EMAGB   , EMAG    , EMBGB   ,
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLM    ,
     9          EML     , EMLS    , EMT     , ESO     , ELEFP   , FOK
      COMMON    H       , HJT     , HKAG    , HKBG    , HKGM1   , HKGM2   ,
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,
     3          HOPE    , HT      , IACV    , IBLW    , IBLK    , IP      ,
     4          IGM     , INT     , ISET    , ISPRO   , K       , K1
      COMMON    K2      , KAP     , KDSCT   , KDS     , KL      , KR1     ,
     6          KR      , KTBCT   , KTB     , KYP1    , KKP     , L       ,
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPSCT   ,
     8          LSW     , MBU     , MFDO    , MFP     , MGDO    , MM      ,
     9 N      , MOP     , MTHT    , NACV    , NB      , NCIK    , NCTS
      COMMON    NDIAG   , NDS     , NGS     , NIB     , NIS     , NLST    ,
     1          NNA     , NNB     , NNDS    , NNN     , NNP     , NN      ,
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      ,
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,
     4          PAS     , PBB     , PBMB    , PBOB    , PBO     , PB
      COMMON    PBS     , PHIAB   , PHIPA   , PHI     , PINT    , PL      ,
     6          PL1     , PO      , PS      , PT      , Q       , QIO     ,
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      ,
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , RSP     ,
     9          REM     , REMS    , RESLIM  , RESO    , RESZ    , RHOGB
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   ,
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      ,
     3          RVB     , RV      , RVS     , S       , S1      , S2      ,
     4          S3      , S4      , SA      , SB      , SGM     , SIG
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,
     6          SMLE    , SMLF    , SMLG    , SM      , SOJ1    , SOJ2    ,
     7          SOP     , SO      , SOSM    , SS      , SSM     , SZO     ,
     8          T       , TB      , TBRAY   , TBRAY1  , TGMB    , TGO     ,
     9          TG      , TGS     , THIM    , THIO    , THT     , THIS
      COMMON    THOB    , THOO    , THO     , THOS    , TK      , TKT     ,
```

```
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR     ,
     3          VBD     , VBDS    , VBM     , VBMSQ   , VB      , VBSQ    ,
     4          VBS     , VGD     , VG      , VGSQ    , VGS     , VIAG
      COMMON    VIALB   , VIAL    , VIBG    , VIBLB   , VIBL    , VIGM    ,
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLD     ,
     7          VL      , VLSQ    , VLS     , VS      , VSS     , WAGB    ,
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLR    ,
     1          XINT    , XP      , XS      , XX      , XXA     , YI      ,
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1         C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TPRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-110)1,110,1
    1 CALL DUMP
C
C
C     PRINT THROAT CONDITIONS.
C
  110 WRITE (6,9110)
      NSTMT=9999
      WRITE (6,1001) XS,PS,RS,VBS,AS,TGS,TLS,VGS,VLS
 1175 WRITE (6,1002) VSS,SS,DD,RVS,RAS,ALPHS,BETAS,
     1       ZMGS,ZMLS
 1176 WRITE (6,1003) RHOGS,RHOLS,WAGS,WBGS,WGS,
     1       PAS,PBS,HLAS,HLBS
 1177 WPITE (6,1004) SIGS,CGMS,CLMS,VIGMS,VILMS,
     1       HKGMS,REMS,CDMS,HMS
 1178 WRITE(6,1007) YOS,WOMS,THOS,DELOS,DLSOS,
     1       RDOMS,CFOMS,TWOMS,VBDS
      IF(MGRO-1)497,1180,497
C
C     LINE 8 OF OUTPUT CONTAINS ADDITIONAL QUANTITIES COMPUTED  FOR
C       ANNULAR NOZZLE.
C
 1180 WRITE (6,1008) YIS,WIMS,THIS,DELIS,DLSIS,RDIMS,
     1       CFIMS,TWIMS
  497 NSTMT=497
      RETURN
C
C     FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
C
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,1P9E14.4)
 1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HD,12X,2HRV,12X,2HRA,9X,
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,1P9E14.4)
 1003 FORMAT(1H0,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,1P9E14.4)
 1004 FORMAT(1H0,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,10X,4HVIGM,10X,
     14HVILM,11X,3HKGM,11X,3HREM,11X,3HCDM,12X,2HHM,/,6X,1P9E14.4)
 1007 FORMAT(1H0,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,
     19X,5HREDOM,10X,4HCFOM,10X,4HTWOM,11X,3HVBD,/,6X,1P9E14.4          )
 1008 FORMAT(1H0,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*I,9X,
     15HREDIM,10X,4HCFIM,10X,4HTWIM,/,6X,1P8E14.4)
 9110 FORMAT(1H0,7X,24HTHROAT CONDITIONS FOLLOW)
      END
                      SUBROUTINE DIAGNO
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
```

```
     6           CFOMS  , CGMB   , CGM    , CGMS   , CLMB   , CLM    ,        DIAG0130
     7           CLMS   , CSAVE  , D      , D2     , DA     , DATE   ,        DIAG0140
     8           DD     , DELIM  , DELI   , DELIS  , DELOM  , DELO   ,        DIAG0150
     9           DELOS  , DELSI  , DFLSO  , DELTM  , DELT   , DELV2           DIAG0160
      COMMON     DEMAGB , DEMAG  , DEMBGB , DEMBG  , DEMGB  , DINT   ,        DIAG0170
     1           DLSIS  , DLSOS  , DO     , DP1    , DP     , DRAY   ,        DIAG0180
     2           DPI    , DRO    , DR     , DS1    , DSAVE  , DSLIM  ,        DIAG0190
     3           DSMAX  , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,        DIAG0200
     4           DSRES  , DS     , DSX1   , DSX2   , DTG1   , DTGB            DIAG0210
      COMMON     DTG    , DTHI   , DTHO   , DTL1   , DTLB   , DTL    ,        DIAG0220
     6           DT     , DVBSQ  , DVGSQ  , DVLSQ  , DX     , DYI    ,        DIAG0230
     7           DYO    , EB     , EDS    , EMAGB  , EMAG   , EMBGB  ,        DIAG0240
     8           EMBG   , EMGB   , EMG    , EMGS   , EML3   , EMLM   ,        DIAG0250
     9           EML    , EMLS   , EMT    , ESO    , FLEEP  , FUX             DIAG0260
      COMMON     H      , HJI    , HKAG   , HKBG   , HKGM1  , HKGM2  ,        DIAG0270
     1           HKGM   , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   ,        DIAG0280
     2           HLB1   , HLBM   , HLP    , HLDS   , HM     , HMS    ,        DIAG0290
     3           HOPE   , HT     , IACV   , IBLW   , IBLX   , IBW    ,        DIAG0300
     4           IJH    , INT    , ISPT   , IZERO  , K      , K1              DIAG0310
      COMMON     K2     , KAP    , KDSCT  , KDS    ,.KL     , KR1    ,        DIAG0320
     6           KR     , KTBCT  , KTB    , KXP1   , KXP    , L      ,        DIAG0330
     7           L1     , L2     , LCT1   , LCT2   , LL     , LPGCT  ,        DIAG0340
     8           LSW    , MBU    , MFPO   , MFP    , MGRO   , MM     ,        DIAG0350
     9 N       , MOP    , MPHT   , NACV   , NB     , NCLK   , NCTS            DIAG0360
      COMMON     NDIAG  , NDS    , NGG    , NTB    , NIS    , NLST   ,        DIAG0370
     1           NNA    , NNB    , NNDS   , NNN    , NNP    , NN     ,        DIAG0380
     2           NNSOO  , NNSO   , NNS    , NP     , NSO    , NS     ,        DIAG0390
     3           P      , P10    , P11    , PAB    , PAMB   , PA     ,        DIAG0400
     4           PAS    , PBB    , PBMB   , PBOB   , PBO    , PB              DIAG0410
      COMMON     PBS    , PHIAB  , PHIBA  , PHI    , PINT   , PL     ,        DIAG0420
     6           PL1    , PO     , PS     , PT     , Q      , QID    ,        DIAG0430
     7           R1     , RA     , RAS    , RAXO   , RAX    , RB     ,        DIAG0440
     8           RC     , RDELIM , RDELOM , RDIMS  , RDOMS  , REF    ,        DIAG0450
     9           REM    , REMS   , RESLIM , RESO   , RESZ   , RHOGB           DIAG0460
      COMMON     RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,        DIAG0470
     1           RIM    , RI     , RM     , ROALB  , ROAL   , ROBLB  ,        DIAG0480
     2           ROBL   , ROM    , RO     , R      , RSLIM  , RS     ,        DIAG0490
     3           RVB    , RV     , RVS    , S      , S1     , S2     ,        DIAG0500
     4           S3     , S4     , SA     , SB     , SGN    , SIG             DIAG0510
      COMMON     SIGS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,        DIAG0520
     6           SMLE   , SMLF   , SMLG   , SM     , SOJ1   , SOJ2   ,        DIAG0530
     7           SOP    , SO     , SOSM   , SS     , SZM    , SZO    ,        DIAG0540
     8           T      , TB     , TBRAY  , TBRAY1 , TGMB   , TGO    ,        DIAG0550
     9           TG     , TGS    , THIM   , THIO   , THI    , THIS            DIAG0560
      COMMON     THOM   , THOO   , THO    , THOS   , TK     , TKT    ,        DIAG0570
     1           TLMB   , TLO    , TL     , TLS    , TST    , TWIM   ,        DIAG0580
     2           TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAR    ,        DIAG0590
     3           VBD    , VBDS   , VBM    , VBMSQ  , VB     , VBSQ   ,        DIAG0600
     4           VBS    , VGO    , VG     , VGSQ   , VGS    , VIAG            DIAG0610
      COMMON     VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,        DIAG0620
     6           VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,        DIAG0630
     7           VL     , VLSQ   , VLS    , VS     , VSS    , WAGB   ,        DIAG0640
     8           WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,        DIAG0650
     9           WBL    , WGB    , WG     , WGS    , WIM    , WIMS            DIAG0660
      COMMON     WOM    , WOMS   , X      , X10    , X11    , XCLK   ,        DIAG0670
     1           XINT   , XP     , XS     , XX     , XXA    , YI     ,        DIAG0680
     2           YIS    , YO     , YOS    , ZZZ    , NSTMT                    DIAG0690
      DIMENSION PL(10)                                                        DIAG0700
       DIMENSION NDRAY(75)                                                    DIAG0710
      DIMENSION DATE(5),CASE(3),DID(8),XP(2,75),PL1(10),                      DIAG0720
     1        C(6),YP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAYDIAG0730
     21(100),DRAY(75),HT(18),DINT(8)                                          DIAG0740
      EQUIVALENCE (NDRAY(1),DRAY(1))                                          DIAG0750
      IF(NSTMT-497)1,497,2                                                    DIAG0760
    1 CALL DUMP                                                               DIAG0770
    2 IF(NSTMT-529)1,529,1                                                    DIAG0780
  497 NSTMT=9999                                                              DIAG0790
      IF(NDIAG-1)10,498,10                                                    DIAG0800
  498 DO 499 I=1,75                                                           DIAG0810
      DRAY(I)=99999.                                                          DIAG0820
  499 CONTINUE                                                                DIAG0830
      LSW=0                                                                   DIAG0840
```

```
      GO TO(501,502,503,504,505,506,507,508,509,510,511,512,513,514,
     1      515,516,517,518,519,520,521,522,523,524,525,526,527,528,
     2      529),LL
C
C    DIAGNOSTIC OUTPUT.    ENTRY IS MADE TO SET CERTAIN
C       SETS OF OUTPUT VALUES INTO THE ARRAY DRAY DEPENDING
C       ON THE VALUE OF LL, WHICH IS SET IN VARIOUS POINTS THROUGHOUT
C       THE MAIN PROGRAM.
C
  529 DRAY(54)=REF
      NSIM=9999
      DRAY(45)=VILB
  528 DRAY(53)=Q
      DRAY(38)=ABAR
      DRAY(47)=RHOLB
  527 DRAY(46)=RHOGB
  526 DRAY(39)=TB
  525 DRAY(44)=EMLB
      DRAY(43)=EMGB
      DRAY(37)=RJ
  524 DRAY(42)=BETAB
      DRAY(41)=ALPHAB
      DRAY(50)=WGB
      DRAY(49)=WHGB
  523 DRAY(48)=WAGB
  522 DRAY(52)=PBB
  521 DRAY(51)=PAB
  520 DRAY(70)=CFIM
      DRAY(69)=RDELIM
      DRAY(71)=TWIM
      DRAY(61)=CFOM
      DRAY(60)=RDELOM
      DRAY(36)=HM
      DRAY(35)=CD
  519 DRAY(34)=REM
  518 DRAY(63)=VBD
      DRAY(56)=WOM
      DRAY(59)=DELSO
      DRAY(58)=DELO
      DRAY(57)=THO
      DRAY(62)=TWOM
      DRAY(68)=DELSI
      DRAY(67)=DELI
      DRAY(66)=THI
      DRAY(65)=WIM
  517 DRAY(5)=A
      DRAY(12)=D
      DRAY(28)=SIG
  516 DRAY(14)=RA
      DRAY(9)=VL
      DRAY(4)=VG
  515 DRAY(1)=X
      DRAY(30)=CLM
      DRAY(29)=CGM
      DRAY(31)=VIGM
      DRAY(32)=VILM
      DRAY(33)=HKGM
      GO TO 1511
  514 DRAY(33)=HKGM
      DRAY(32)=VILM
  513 DRAY(31)=VIGM
      DRAY(29)=CGM
      DRAY(30)=CLM
  512 DRAY(63)=VBD
      DRAY(56)=WOM
      DRAY(59)=DELSO
      DRAY(58)=DELO
      DRAY(57)=THO
      DRAY(62)=TWOM
      DRAY(68)=DELSI
      DRAY(67)=DELI
      DRAY(66)=THI
```

```
      DRAY(65)=WIM
      DRAY(5)=A
      DRAY(12)=D
      DRAY(28)=SIG
      DRAY(14)=PA
      DRAY(9)=VL
      DRAY(8)=VG
      DRAY(1)=X
 1511 DRAY(55)=YO
      DRAY(54)=YI
  511 DRAY(11)=S
      DRAY(4)=VB
      DRAY(10)=VS
      DRAY(5)=A
      DRAY(27)=HLB
  510 DRAY(26)=HLA
  509 DRAY(13)=RV
      DRAY(18)=EML
      DRAY(17)=EMG
      DRAY(20)=RHOL
  508 DRAY(19)=RHOG
      DRAY(3)=R
  507 DRAY(16)=BETA
      DRAY(15)=ALPHA
      DRAY(23)=WG
      DRAY(22)=WBG
  506 DRAY(21)=WAG
  505 DRAY(25)=PB
  504 DRAY(24)=PA
  503 DRAY(7)=TL
  502 DRAY(6)=TG
  501 DRAY(2)=P
      NDRAY(72)=NNA
      NDRAY(73)=NIS
      NDRAY(74) = NIB
      IF(NDIAG-1)540,550,540
  540 WRITE (11) DRAY
      NNN=NNN+1
      DRAY(10)=0.0
C     WRITE(18) (DRAY(J),J=1,10)
      MM=MM+1
      GO TO 63
C
C  DIAGNOSTIC OUTPUT - VARIABLES NOT YET COMPUTED THIS
C    ITERATION ARE SET TO 10E5. PRINT OUT NINE LINES
C    OF OUTPUT.
C
  550 WRITE (6,1001)  (DRAY(I),I=1,9)
  551 WRITE (6,1002)  (DRAY(I),I=10,18)
  552 WRITE (6,1003)  (DRAY(I),I=19,27)
  553 WRITE (6,1004)  (DRAY(I),I=28,36)
  554 WRITE (6,1005)  (DRAY(I),I=29,45)
  555 WRITE (6,1006)  (DRAY(I),I=46,54)
  556 WRITE (6,1007)  (DRAY(I),I=55,63)
  557 WRITE (6,1008)  (DRAY(I),I=64,71)
  558 CONTINUE
      WRITE (6,1009) NNA,NIS,NIB
   10 NSTMT=10
      RETURN
   63 NSTMT=63
      RETURN
C
C   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
C
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,9E06.4)
 1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HD,12X,2HRV,12X,2HPA,9X,
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,9E14.4)
 1003 FORMAT(1H0,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,9E14.4)
 1004 FORMAT(1H0,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,10X,4HVIGM,10X,
     14HVILM,11X,3HKGM,11X,3HREM,11X,3HCDM,12X,2HHM,/,6X,1P9E14.4)
```

```
 1005 FORMAT(1H0,12X,2HRB,12X,2HAB,12X,2HTB,11X,3HRVB,9X,5HALPHB,
     19X,5HBETAB,11X,3HMGB,11X,3HMLB,10X,4HVILB,/,6X,9E14.4   )
 1006 FORMAT(1H0,10X,4HROGB,10X,4HROLB,10X,4HWAGB,10X,4HWBGB,
     111X,3HWGB,11X,3HPAB,11X,3HPBB,13X,1HQ,11X,3HREF,/,6X,9E14.4)
 1007 FORMAT(1H0,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,
     19X,5HREDOM,10X,4HCFOM,10X,4HTWOM,11X,3HVBD,/,6X,9E14.4)
 1008 FORMAT(1H0,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*1,9X,
     15HREDIM,10X,4HCFIM,10X,4HTWIM,/,6X,8E14.4)
 1009 FORMAT(1H0 ,10X ,3HNNA   ,9X ,3HNIS   ,9X, 3HNIB /2X, 3(6X,I6))
C1032 FORMAT(1H1,120X,5HPAGE ,I3,/,1X,15HREAL TWO-PHASE ,
C    1      26H TWO-COMPONENT NOZZLE FLOW,// )
      END
      SUBROUTINE WRITE      (DVGSQ,DTL,RHOLM,DVLSQ,DEMAG,DEMBG,
     1      DELV2,EMG,HLA1,CAG1,DELT,HLB1,CBG1,SM,AM,BM,DX,DS)
      WRITE (6,9231) DVGSQ,DTL,RHOLM,DVLSQ,DEMAG,DEMBG,
     1      DELV2,EMG,HLA1,CAG1,DELT,HLB1,CBG1,SM,AM,BM,DX,DS
      RETURN
 9231 FORMAT(1H0,12X,5HDVGSQ,14X,3HDTL,12X,5HRHOLM,12X,5HDVLSQ,12X,
     15HDEMAG,12X,5HDEMBG,12X,5HDELV2,/,1X,1P7E17.6,//,15X,3HEMG,14X,
     1   3HLA1,13X,4HCAG1,13X,4HDELT,14X,3HLB1,13X,4HCBG1,
     1     15X,2HSM,/,1X,7E17.6,//,
     2     16X,2HAM,15X,2HBM,15X,2HDX,15X, 2HDS,/,1X,7E17.6)
      END
      SUBROUTINE OUTPUT(N,LPG,MGEO)
C SUBROUTINE TO READ SAVED PRINT LINES FROM LOGICAL
C    TAPE 20 AND PRINT THEM ON FORTARAN OUTPUT TAPE.
      DIMENSION DRAY(75),NDRAY(75)
      EQUIVALENCE (DRAY(1),NDRAY(1))
      REWIND 11
      L=1
    1 IF(N)99,99,2
    2 READ (11)DRAY
      IF(L)5,5,4
    4 WRITE (6,1032) LPG
      LPG=LPG+1
      L=0
       GO TO 6
    5 WRITE (6,998)
      L=1
    6 WRITE  (6,1001)  (DRAY(I),I=1,9)
      WRITE  (6,1002)  (DRAY(I),I=10,18)
      WRITE  (6,1003)  (DRAY(I),I=19,27)
      WRITE  (6,1004)  (DRAY(I),I=28,36)
      WRITE  (6,1005)  (DRAY(I),I=37,45)
      WRITE  (6,1006)  (DRAY(I),I=46,54)
      WRITE  (6,1007)  (DRAY(I),I=55,63)
      IF(MGEO) 7,8,7
    7 WRITE  (6,1008)  (DRAY(I),I=64,71)
    8 CONTINUE
      WRITE  (6,1009)  (NDRAY(I),I=72,74)
       N=N-1
      GO TO 1
   99 REWIND 11
      RETURN
  998 FORMAT(1H0,///   )
C1000 FORMAT(6X,12E14.4)
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,9E14.4)
 1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HD,12X,2HRV,12X,2HRA,9X,
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,9E14.4)
 1003 FORMAT(1H0,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,9E14.4)
 1004 FORMAT(1H0,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,10X,4HVIGM,10X,
     14HVILM,11X,3HKGM,11X,3HREM,11X,3HCDM,12X,2HMS,/,6X,9E14.4)
 1005 FORMAT(1H0,12X,2HRB,12X,2HAB,12X,2HTB,11X,3HRVB,9X,5HALPHB,
     19X,5HBETAB,11X,3HMGB,11X,3HMLB,10X,4HVILB,/,6X,9E14.4)
 1006 FORMAT(1H0,10X,4HROGB,10X,4HROLB,10X,4HWAGB,10X,4HWBGB,
     111X,3HWGB,11X,3HPAB,11X,3HPBB,13X,1HQ,11X,3HREF,/,6X,9E14.4)
 1007 FORMAT(1H0,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,
     19X,5HREDOM,10X,4HCFOM,10X,4HTWOM,11X,3HVBD,/,6X,9E14.4)
 1008 FORMAT(1H0,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*1,9X,
     15HREDIM,10X,4HCFIM,10X,4HTWIM,/,6X,8E14.4)
```

```
 1009 FORMAT(1H0,10X,3HNNA,9X,3HNIS,9X,3HNIB              /,2X,
     1      3(6X,I6))
 1032 FORMAT(1H1,120X,5HPAGE ,I3,/,1X,15HREAL TWO-PHASE ,
     1       26H TWO-COMPONENT NOZZLE FLOW,// )
      END
      SUBROUTINE XPTBL(XP)
C   SUBROUTINE TO PRINT OUT XP TABLE C
      DIMENSION XP(2,75)
  792 L1=1
      L2=8
  794 WRITE (6,793)
C   PRINT OUT NEW X(P) TABLE
  795 WRITE (6,909)  (XP(1,MT),MT=L1,L2)
      WRITE (6,917)  (XP(2,MT),MT=L1,L2)
      IF (L2-72) 796,797,798
  796 L1=L1+8
      L2=L2+8
      GO TO 795
  797 L1=L1+8
      L2=L2+3
      GO TO 795
  798 RETURN
  793 FORMAT(1H1,//,50X,14HNEW X(P) TABLE,///)
  909 FORMAT(1H0,3X,5HPRESS,1X,1P8E15.4)
  917 FORMAT(1H ,7X,1HX,1X,1P8E15.4)
      END
      SUBROUTINE TABLE
C     GENERATE NOZZLE FLOW TABLE TAPE SUBROUTINE
C
C
      DIMENSION TVAR(14,2,50),C(6),XVAR(4,35),TSAV1(35,4,35),
     1      TSAV2(35,4,35)
      COMMON TSAV1,TSAV2
      DO 1 I=1,14
      DO 1 J=1,2
      DO 1 K=1,50
      TVAR(I,J,K)=1.0E5
    1 CONTINUE
      DO 2 L=1,35
      DO 2 I= 1,4
      DO 2 K=1,35
      TSAV1(L,I,K) = 100000.
      TSAV2(L,I,K) = 100000.
    2 CONTINUE
      DO 25 I = 1,4
      DO 25 J=1,35
C     THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENSIO
      XVAR (I,J) = 100000.
   25 CONTINUE
    3 L=1
      I=1
      K=1
      ICARD=0
    4 READ (5,901)  (C(M),M=1,6)
      ICARD=ICARD+1
      IF (C(3))5,6,5
    6 IF(C(2)-1.0) 11,11,5
    5 DO 10 M = 1,5,2
      IF(C(M)+C(M+1) - 199999.)8,13,13
    8 TSAV1(L,I,K)  = C(M)
      TSAV2(L,I,K)  = C(M+1)
      IF(K-35) 9,9,26
    9 K = K+1
   10 CONTINUE
      GO TO 4
   26 WRITE (6,900) I,L,K
      GO TO 37
   11 XV = C(2)
      XVAR(I,L) = C(1)
      GO TO 4
   13 IF(XV)  15,14,15
   14 L = L+1
```

```
      K=1
      IF(L-35) 4,4, 27
C     THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENSIO
   15 IF(I-4) 16,17,17
   16 L=1
      I = I + 1
      K=1
      GO TO 4
   27 WRITE (6,927) I
      GO TO 37
   17 CONTINUE
      REWIND 12
      WRITE (12) XVAR
      WRITE (12) TSAV1
      WRITE (12) TSAV2
C  NEXT CARD IS FIRST CARD OF TVAR ARRAY
      DO 38 I=1,14
      K=1
   29 READ (5,901) (C(L),L=1,6)
      ICARD=ICARD+1
      DO 34 L=1,5,2
      IF(C(L)+C(L+1)-199999.)32,30,30
   30 TVAR(I,1,K)=100000.
      TVAR(I,2,K)=100000.
      GO TO 38
   32 TVAR(I,1,K)=C(L)
      TVAR(I,2,K)=C(L+1)
      IF(K-50) 33,37,37
   33 K=K+1
   34 CONTINUE
      GO TO 29
   38 CONTINUE
   36 WRITE (12) TVAR
      CSAVE=0.0
      READ (5,901) (C(L),L=1,6)
      ICARD=ICARD+1
      DO 1036   I=1,6
 1036 CSAVE = CSAVE + C(I)
      IF(CSAVE)37,1037,37
   37 CALL INTRP(V,20,1.0,P)
      CALL DUMP
      CALL EXIT
 1037 CONTINUE
      ENDFILE 12
      REWIND 12
      RETURN
  900 FORMAT(1H0,7X,19HERROR IN INPUT DATA,3I6)
  901 FORMAT (6E12.6)
  927 FORMAT(1H0,7X,36HEXCEEDING MAXIMUM TEMPERATURE INPUT ,
     117HFOR N =,I3)
      END
      SUBROUTINE INTRP(VAR,N,T,P)
C
C   IF N=0, READ IN ALL TABLES, SET UP T ARRAY, AND EXIT.
C   IF N= 20 WRITE OUT ALL TABLES AND EXIT.
C   IF N=1 THRU 4, GET APPROPRIATE TABLES FROM TAPE,
C      INTERPOLATE FOR VALUE OF VAR AND EXIT.
C   IF N=5 THRU 13, INTERPOLATE FOR VALUE OF VAR AND EXIT.
C
      DIMENSION TVAR(14,2,50),TVAR1(35,4,35),TVAR2(35,4,35)
     1      ,TRAY(4,35),H(14)
      COMMON TVAR1,TVAR2,TVAR
      ISW=0
      IF(N) 1,1,10
    1 K=1
      REWIND 12
      READ (12) TRAY
      READ (12) TVAR1
      READ (12) TVAR2
C
C   T ARRAY HAS BEEN SET UP, NO. OF T RECORDS (K) IS SET, NOW
C         PROCEED TO BRING IN PERMANENT ARRAYS.
```

```
C
      READ (12) TVAR
      RETURN
   10 IF(N-20) 100,12,11
   11 WRITE (6,911)
      CALL EXIT
C  WRITE OUT TABLES FOR N=20, T IS PAGE COUNT.
   12 CALL ADATA
      LCT1=0
      LPGCT=T
      WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      DO 30 L=1,14
   13 NT=1
   14 TEST1=TVAR(L,1,NT)+TVAR(L,2,NT)
      IF(TEST1-2.0*99999.)15,15,16
   15 NT=NT+1
      IF(NT-50)14,14,1000
   16 TVAR(L,1,NT)=0.0
      TVAR(L,2,NT)=0.0
      IF(NT-1) 515,520,515
C  NO INPUT THIS TABLE
  520 WRITE (6,9520) H(L)
      LCT1 = LCT1+4
      GO TO 530
  515 NT=NT-1
      WRITE (6,916) H(L)
      L1=1
      L2=AMINO(8,NT)
      LT=1
   18 WRITE (6,918) H(L), (TVAR(L,2,LK),LK=L1,L2)
      WRITE (6,919)  (TVAR(L,1,LK),LK=L1,L2)
      IF(L2-NT) 19,20,20
   19 L1=L1+8
      L2=AMINO(L2+8,NT)
      LT=LT+1
      GO TO 18
   20 LCT1=LT*3+3+LCT1
  530 IF(LCT1-52) 30,21,21
   21 WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      LCT1=3
   30 CONTINUE
      REWIND 12
      DATA H(1)/4H CAG/
      DATA H(2)/4H CBG/
      DATA H(3)/4H WAG/
      DATA H(4)/4H WBG/
      DO 50 L=1,4
      IF (TRAY (L,1)-99999.) 29,29,50
   29 WRITE (6,920) LPGCT
   31 WRITE (6,915) H(L)
      LPGCT=LPGCT+1
      LCT1=3
      DO 45 KK=1,35
      IF (TRAY (L,KK)-99999.) 32,32,45
   32 WRITE (6,934) TRAY(L,KK)
      LCT1=LCT1+3
      NCT=1
   34 TEST1=TVAR1(KK,L,NCT)+TVAR2(KK,L,NCT)
      IF(TEST1-2.0*99999.) 35,36,36
   35 NCT=NCT+1
      IF(NCT-35)34,34,1000
   36 NCT=NCT-1
      L1=1
      L2=AMINO(8,NCT)
   37 CONTINUE
   38 DO 63 LT=L1,L2
      IF(TVAR2(KK,L,LT)-100000.)63,60,63
   60 TVAR1(KK,L,LT)=0.0
      TVAR2(KK,L,LT)=0.0
   63 CONTINUE
```

```
      WRITE (6,938) H(L), (TVAR2(KK,L,LT),LT=L1,L2)
   39 WRITE (6,939) (TVAR1(KK,L,LT),LT=L1,L2)
      LCT1=LCT1+3
      IF(LCT1-52)66,65,65
   65 WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      LCT1=3
   66 IF(L2-NCT)40,41,41
   40 L1=L1+8
      L2=AMIN0(L2+8,NCT)
      GO TO 38
   41 IF(LCT1-52)45,42,42
   42 WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      LCT1=3
   45 CONTINUE
   50 CONTINUE
      IF(IBW-1) 1047, 1046, 1047
 1046 N=0
 1047 RETURN
C  N=1 THRU 18 - INTERPOLATE ROUTINE
  100 IF(N-4) 101,101,150
  101 DO 104 I=1,35
      IF(TRAY(N,I)-T) 104,105,105
  104 CONTINUE
      GO TO 120
  105 IF(I-1) 106,120,106
  106 IM1=I-1
      TK=TRAY(N,I)
      TK1=TRAY(N,IM1)
      DO 107 J1=1,35
      IF(TVAR1(IM1,N,J1)-P) 107,107,108
  107 CONTINUE
      GO TO 120
  108 IF(J1-1) 109,120,109
  109 IF(TVAR1(IM1,N,J1)+TVAR2(IM1,N,J1)-2.0*99999.) 110,120,120
  110 JM1=J1-1
      DIFPT=TVAR1(IM1,N,J1)-TVAR1(IM1,N,JM1)
      DIFP1=      TVAR1(IM1,N,J1)-P
      PC1=-(DIFP1/DIFPT)*(TVAR2(IM1,N,J1)-TVAR2(IM1,N,JM1))+
     1TVAR2(IM1,N,J1)
      DO 111 J2=1,35
      IF(TVAR1(I,N,J2)-P) 111,111,112
  111 CONTINUE
      GO TO 120
  112 IF(J2-1) 113,120,113
  113 JM2=J2-1
      IF(TVAR1(I,N,J2)+TVAR2(I,N,J2)-2.*99999.) 114,120,120
  114 DIFPT=TVAR1(I,N,J2)-TVAR1(I,N,JM2)
      DIFP1=      TVAR1(I,N,J2)-P
      PC2 =-(DIFP1/DIFPT)*(TVAR2(I,N,J2)-TVAR2(I,N,JM2))+TVAR2(I,N,J2)
      VAR=(T-TK1)/(TK-TK1)*(PC2-PC1)+PC1
  130 RETURN
  120 N=0
      IBW=1
      GO TO 12
  150 N=N-4
      IF(N-15) 155,1000,1000
  155 CONTINUE
      DO 151 I=1,50
      IP=I
      IF(TVAR(N,1,I)-T) 151,151,152
  151 CONTINUE
      GO TO 120
  152 IF(TVAR(N,1,I)+TVAR(N,2,I)-2.0*99999.) 153,120,120
  153 IF(IP-1) 154,120,154
  154 IP1=IP-1
      VAR=((T-TVAR(N,1,IP1))/(TVAR(N,1,IP)-TVAR(N,1,IP1)))
     1*(TVAR(N,2,IP)-TVAR(N,2,IP1))+TVAR(N,2,IP1)
      GO TO 130
 1000 CONTINUE
      CALL OUTPUT
```

```
      CALL DUMP
      RETURN
  911 FORMAT(1H0,7X,33HILLEGAL CALLING SEQUENCE TO INTRP)
  916 FORMAT(1H0,56X,11HINPUT TABLE,2X,A5,/)
  918 FORMAT(1H0,A6,1P8E15.6)
  919 FORMAT (1H ,2X,4HTEMP,1P8E15.6      )
  920 FORMAT(1H1,/,120X,4HPAGE,2X,I3)
  934 FORMAT(1H0,40X,14HTEMPERATURE = ,F12.4,//)
  938 FORMAT(1H0,3X,A6,1P8E15.6)
  939 FORMAT(1H ,3X,5HSTRESS ,1X, 1P8E15.6)
 9520 FORMAT(1H0,/,1H0,7X,18HNO INPUT FOR TABLE, A6)
      END
C*****************************************************************
      SUBROUTINE DUMP
      CALLEXIT
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE ADATA
      DIMENSION HT(18),H(14),HT1(18),H1(14)
      COMMON HT,H
      DATA HT1/4H CAG,4H CBG,4H WAG,4H WAG,4H CAL,
     1          4H CBL,4H  LA,4H  LB,4H PBO,4HROAL,
     2          4HROBL,4H KAG,4H KBG,4HVIAL,4HVIBL,
     3          4HVIAG,4HVIBG,4H SIG/
      DATA H1/4H CAL,4H CBL,4H HLA,4H HLB,4H PBO,
     1         4HROAL,4HROBL,4H KAG,4H KBG,4HVIAL,
     2         4HVIBL,4HVIAG,4HVIBG,4H SIG/
      DO 10 I=1,18
         HT(I)=HT1(I)
   10 CONTINUE
      DO 20 I=1,14
         H(I)=H1(I)
   20 CONTINUE
      RETURN
      END
```

LIST OF REFERENCES

1. National Aeronautics and Space Administration, Technical Report 32-987, Acceleration of Liquids in Two-Phase Nozzles by D. G. Elliott and E. Weinberg, July 1968.

2. AIAA/SAE/ASME 17th Joint Propulsion Conference, Report AIAA-81-1604, Biphase Turbine for Marine Propulsion by L. Hays, July 1981.

3. Tables of Thermal Properties of Gases, National Bureau of Standards Circular 564, November 1, 1955.

4. Flow Measurement/Instruments and Apparatus, Part 5 - Measurement of Quantity of Materials, The American Society of Mechanical Engineers, February 1959.

BIBLIOGRAPHY

Berstein, A., Heiser, W. H. and Hevenor, C., Compound-Compressible Nozzle Flow, Journal of Applied Mechanics Paper No. 67-APM-L, November 1966.

Cerini, D. J., A Two-Phase Rotary Separator Demonstration System for Geothermal Energy Conversion, 12th IECEC Paper No. 770135.

Cerini, D. J. and Hays, L. G., Power Production from Geothermal Brine with the Rotary Separator Turbine, American Institute of Aeronautics and Astronautics, Inc. Paper No. 809156, 1980.

Colwell, G. T., Low Density Nozzle Flow, The American Society of Mechanical Engineers Paper No. 68-WA/FE-9, August 1968.

Dash, S. M. and Thorpe, R. D., Shock-Capturing Model for One- and Two-Phase Supersonic Exhaust Flow, American Institute of Aeronautics and Astronautics Paper No. 80-1254, February 1981.

Ganic, E. M. and Rohsenow, W. M., On the Mechanism of Liquid Drop Deposition in Two-Phase Flow, The American Society of Mechanical Engineers Paper No. 76-WA/HT-18, July 1976.

Hays, L. and Neal, J., Biphase Turbines for Diesel Bottoming, Energy Research and Development Administration Paper No. 779077.

Hiley, P. E. and Wallace, H. W. and Booz, E. E., Nonaxis-symmetric Nozzles Installed in Advanced Fighter Aircraft, AIAA/SAE 11th Propulsion Conference Paper No. 75-1316, August 1973.

Keenan, J. H. and Kaye, J., Gas Tables, John Wiley & Sons, Inc., 1948.

Lewis, W. G. E., Propelling Nozzle Research, lecture given to the Society on April 23, 1963.

Li, W. and Lam, S., Principles of Fluid Mechanics, Addison-Wesley Publishing Co., 1964.

Muench, R. K. and Ford, A. E., A Water-Augmented Air Jet for the Propulsion of High-Speed Marine Vehicles, paper presented at the AIAA 2nd Advanced Marine Vehicles and Propulsion Meeting, Seattle, Wash., May 1969.

Nunn, R. H. and Brandt, H., Aerodynamic Throttling of Two-Dimensional Nozzle Flows, August 1970.

Replogle, J. A., Myers, L. E. and Brust, K., Flow Measurements with Fluorescent Tracers, March 1968.

Schlichting, H., Boundary-Layer Theory, McGraw Hill Book Co., 1979.

Shapiro, A. E., The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. 1, The Ronald Press Co., 1953.

Streeter, V. L. and Wylie, E. B., Fluid Mechanics, Seventh Ed., McGraw-Hill Book Co., 1979.

Thornock, R. L. and Brown, E. F., An Experimental Study of Compressible Flow through Convergent-Conical Nozzles, Including a Comparison with Theoretical Results, ASME Publication Paper No. 71-WA/FE-3, June 1971.

Wagner, J. L., A Cold Flow Field Experimental Study Associated with a Two-Dimensional Multiple Nozzle, 1971.

Wagner, W. B. and Owczarek, J. A., An Investigation of the Corner Secondary Flows Generated in Planar Nozzles, The American Society of Mechanical Engineers Paper No. 73-WA/Fles-5, August 1973.

The American Society of Mechanical Engineers Paper No. 80-GT-90, Some Effects of Using Water as a Test Fluid in Fuel Nozzle Spray Analysis, December 1979.

Air Force Systems Command Report SRD-73-161, Techniques for Injection and Acceleration of Particles by Ultra High Speed Gas Jets, February 1974.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 69 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	1
4.	Professor Joseph Sladky, Code 69Zy Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	3
5.	LT Thomas C. Nollie, Jr., USN 14013 Spinning Avenue Gardena, California 90249	2

Thesis
N843
c.1

199545

Nollie

Dual-phase nozzle flow.